**UNIVERSITA' DELLA CALABRIA**

**Dipartimento di Scienze della Terra**

**UNIVERSITA' DEGLI STUDI DELLA CALABRIA**

**Facoltà di Scienze Matematiche Fisiche e Naturali**

***Dottorato di Ricerca in Scienze della Terra XXI Ciclo***

*SETTORE SCIENTIFICO DISCIPLINARE*

***GEO/02 (Geologia stratigrafica e sedimentologica)***

# THE INTERPLAY OF ACCRETIONARY PROCESSES AND MAGMATIC ARCS IN FORMING STRATIGRAPHIC SEQUENCES IN THE CIRCUM-RHODOPE BELT, GREECE AND BULGARIA


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*2005 - 2008*

# 1. Università degli Studi della Calabria

*1.1.*

## *1.2. Dottorato di Ricerca in "Scienze della Terra"*

Riunione Collegio Docenti

**Stralcio di Verbale del 29 Ottobre 2008**

Il giorno **29** (ventinove) del mese di **ottobre** dell'anno **2008** (duemilaotto ), alle **ore 16.00** (sedici), presso la Sala Teleconferenze del Dipartimento di Scienze della Terra, si è riunito il Collegio Docenti del Dottorato di Ricerca in "Scienze della Terra" convocato con prot. n°080000918 dal presidente Prof. F. Russo, per discutere i seguenti punti dell'ordine del giorno:

1. Comunicazioni
2. Presentazione della relazione di fine dottorato in cotutela italo-francese (Fortunato, XX Ciclo);
3. Presentazione delle relazioni di fine Dottorato XXI Ciclo (Caracciolo, Conforti, Folino Gallo, Gramigna, Macchione, Tripodi);
4. Varie ed eventuali.

Sono presenti i seguenti componenti del Collegio Docenti del Dottorato di Ricerca in "Scienze della Terra":

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Il Presidente, constatata la presenza del numero legale, alle 16,20 dichiara aperta la seduta.

O M I S S I S

**3. Presentazione delle relazioni di fine Dottorato XXI Ciclo (Caracciolo, Conforti, Folino Gallo, Gramigna, Macchione, Tripodi)**

O M I S S I S

Il Presidente restringe l'assemblea ai soli membri del Collegio Docenti al fine di valutare la relazione.

Dopo aver ascoltato la relazione, il Collegio esprime il proprio giudizio sulla tesi di dottorato del Dott. **Luca, Piervincenzo CARACCIOLO**:

La tesi di dottorato svolta dal dr. Caracciolo ha avuto per oggetto lo studio stratigrafico, composizionale e geochimico della successione arenitica Terziaria (Eocenico-Oligocenica) del Bacino della Tracia nel Massiccio Rhodopico centrale (Bulgaria) e meridionale (Grecia settentrionale). L'obiettivo fondamentale del dottorato del dr. Caracciolo è stato di dettagliare le relazioni tra sedimentazione clastica derivata dal sistema orogenetico, la sedimentazione vulcanoclastica, la tettonica e la provenienza dei sedimenti clastici.

I risultati raggiunti dal dr. Caracciolo nel corso del suo dottorato, sono stati estremamente lusinghieri sia come mole di dati presentati sia come interpretazione degli stessi, rappresentando una base geologica e stratigrafica di estremo dettaglio. Egli, inoltre, ha mostrato spiccate capacità organizzative, indipendenza e altissime capacità di interazione con numerosi ricercatori italiani e stranieri specialisti dei settori specifici affrontati durante lo svolgimento del lavoro di tesi. In particolare sono da menzionare i proficui periodi di formazione all'Università di Gottingen durante i quali ha perfezionato gli aspetti di geochimica dei sedimenti. L'impegno complessivamente profuso ha portato il dr. Caracciolo non solo a raggiungere ottimi risultati nello specifico lavoro svolto, ma anche a maturare notevoli capacità nell'acquisizione, gestione ed utilizzazione scientifica di dati geologici e sedimentologici. Il giudizio finale pertanto deve essere ampiamente positivo.

Il Collegio Docenti esprime parere ampiamente favorevole per l'ammissione all'esame finale del Dottorato di Ricerca al Dott. **Luca CARACCIOLO.**

O M I S S I S

Non essendoci più punti all'o.d.g., il Presidente dichiara chiusa la seduta alle ore 20.00.

Il segretario verbalizzante | Il Presidente

Prof.$^{ssa}$ Adelaide Mastandrea | Prof. Franco Russo

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## Riassunto

Le rocce sedimentarie rappresentano la principale sorgente di informazioni per accedere alla comprensioni delle condizioni passate della superficie terrestre. Le rocce clastiche possono preservare il detrito proveniente da diversi assetti tettonici, oggi nascoste dall'obliterazione tettonica, i processi di denudazione o erosivi. In alcuni casi la composizione dei sedimenti clastici fornisce le uniche informazioni che riguardano aree sorgenti del passato, e per questo indispensabili nelle ricostruzioni paleogeografiche.

Con l'avvento della teoria della tettonica a placche si è notato che la distribuzione globale dei tipi di roccia può essere spiegata in funzione dell'assetto tettonico. Fu Dickinson, all'inizio degli anni '70 dello scorso secolo a correlare, insieme al suo gruppo di lavoro, la componente scheletrica delle areniti con l'assetto tettonico delle rocce da cui esse derivano. Le analisi petrografiche dei sedimenti sabbiosi risultano quindi di fondamentale importanza nel ricostruire la storia della crosta terrestre e nell'intendere questa come un sistema integrato.

Ad oggi, gli studi di provenienza comprendono le interpretazioni riguardanti i processi che hanno dato origine alla roccia madre e responsabili della loro messa in posto. Zuffa (1984), Morton (1989) e Johnsson (1993) hanno brillantemente dimostrato come la comprensione dei processi pre- e post-deposizionali, che esercitano un controllo sulla composizione dei sedimenti, sia di vitale importanza. Tali processi sono rappresentati sostanzialmente dall'alterazione di tipo meccanico e quelle di tipo chimico, nonché dall'erosione, a loro volta influenzate dal clima, dal rilievo, dall'area sorgente, da processi idrodinamici e di *mixing* e in fine il riciclo e la diagenesi.

In tempi recenti, l'approccio geochimico agli studi di provenienza, ha dimostrato di essere uno strumento efficace, in grado di amplificare i segnali di provenienza celati nelle rocce sedimentarie.

E' stato dimostrato, che la proporzione di elementi immobili, che viene trasferita dalle aree sorgenti ai depositi clastici, attraverso i processi sedimentari, rimane pressoché costante (Taylor e McLennan, 1983; Condie, 1991). L'approccio geochimico risuta essere quindi particolarmente adatto nel caratterizzare la provenienza dei sedimenti, specialmente nell'identificare e determinare il tipo di *terranes*, l'età dei sedimenti e le caratteristiche crostali o del mantello in cui si sono formate le rocce madri dalle quali provengono. L'approccio geochimico risulta essere particolarmente efficace anche nella descrizione dei processi sedimentari, come il *weathering*, il riciclo sedimentario o i processi di selezione, e si integra perfettamente con le informazioni derivanti dalle analisi petrografiche.

Questo lavoro ha quindi l'obiettivo di descrivere, attraverso un approccio multidisciplinare, le relazioni esistenti tra processi accrezionali, la sovrimposizione di un arco magmatico e la risposta sedimentaria delle successioni sedimentarie dell'Eocene-Oligocene accumulatesi nei bacini sedimentari dell'area Circum-Rodopica, tra la Grecia nord-orientale e la Bulgaria sud-orientale.

Non esistono studi pregressi sulle successioni sedimentarie dell'area di studio, ad eccezione di una descrizione generale delle coperture dei Rodopi meridionali fornita dall'Istituto di geologia e mineralogia ellenico (I.G.M.E). E' per questo motivo che la comprensione dei rapporti tra le diverse successioni si è rivelato di vitale importanza nel caratterizzare l'evoluzione dell'area rodopica.

Il massiccio dei Rodopici (MR) è limitato nell'area balcanico egea dalla zona del Vardar ad ovest, dal mar egeo a sud e dalla valle del fiume Maritza a nord. Il MR è un elemento dell'orogene alpino formatosi in seguito a processi di convergenza tra Africa ed Europa dovuti alla chiusura della Paleotetide.

Il massiccio MR è stato generalmente interpretato come un microcontinente formatosi durante la framentazione supercontinente Pangea. Come conseguenza di questo processo di frammentazione si creò l'oceano Paleo-tetideo di cui il MR rappresenta un elemento del suo margine settentrionale. A partire dal Paleozoico e successivamente nel Mesozoico il bordo settentrionale della Paleotetide si sposta verso nord saldandosi con il margine europeo. Questa saldatura avviene per il MR , secondo la ricostruzione di Stampfly e Bore (2004) alla fine del Paleozoico, all'altezza della piattaforma Moesica.

Conteporaneamente alle fasi di chiusura della Paleotetide, sempre secondo Stampfly e Bore (2004), inizia alla fine del Paleozoico l'apertura della Neotetide i cui resti si ritrovano ancora nel mar Ionico. La chiusura della Paleotetide e l'apertura della Neotetide determinarono lungo il bordo europeo la formazione nel Giurassico di relativamente piccoli bacini oceanici (Pindos e Vardar). La successiva chiusura dei due oceani, per convergenza verso nord della placca Africana, sarà l'elemento geodinamico che determinerà l'evoluzione del MR a partire dalla fine del Mesozoico fino al Miocene.

Un'ipotesi alternativa, proposta da Barr et al. ( 1999), vede il MR come frammento continentale pre-Alpino, di età ercinica o pre-cambrica, saldato al margine europeo per chiusura della Paleotetide e successivamente coinvolto nella chiusura della Neotetide e degli associati bacini oceanici mesozoici formatisi nella sua parte settentrionale (Pindos e Vardar). Questi autori, studiando la parte centro meridionale dei Rodopi, propongono che le associazioni metamorfiche siano il risultato di un continuo trasferimento di materiale oceanico e crostale dal *footwall* all' *hangingwall* in seguito ad un continuo processo di subduzione verso nord della Paleoteide.

Indipendentemente dalla disputa sull'evoluzione geodinamica del MR, questo è costituito da una serie di unità metamorfiche di origine continentale, a cui si associano unità miste oceaniche e prodotti da arco insulare oceanico (Ricou et al., 1998). Le unità metamorfiche continentali costituiscono il Supergruppo Pre-Rodopico (Zagorchev,1998a,2004) equivalente all' Unità Tettonica Inferiore (LTU) di Barr et al. (1999). Le rocce di origine oceanica formatesi in un ambiente di arco insulare appartengono al Supergruppo Rodopico (Unità Tettonic Superiore di Barr et al.,1999). Esse sono separate dalle metamorfiti continentali da una successione di miloniti ed ultramiloniti con tessiture indicanti un loro sovrascorrimento verso Sud (Barr et al., 1999). Graniti di età paleozoica - oligocenica tagliano le metamorfiti rodopiche (Ricou et al., 1998).

Le unità metamorfiche di origine continentale hanno una composizione acida-intermedia e sono formate da migmatiti, gneiss e metagraniti. Le metamorfiti delle unità superiori (UTU, di Ricou et al., 1998, o Complesso Variegato, di Haydoutov, 2004) mostrano una maggiore variabilità litologica: Sono presenti micascisti, marmi, anfiboliti, eclogiti , metaofioliti, metagabbri.

Nella sua parte meridionale, in Grecia, il MR è bordato da una fascia di rocce metamorfiche mesozoiche di basso grado ed epimetamorfiche formanti la Cintura Circum-Rhodopica .L'unità inferiore (Makri unit) è composta da marmi ,scisti, gneiss albitici, con associate metadiabasi e serpentiniti( Papadoupolos,1982). L'età di questa unità è compresa tra il Trias ed il Cretacico inferiore. L'unità di Makri è sormontata da una serie epimetamorfica sedimentaria composta da shales, metagrovacche, quarziti (unità di Drimou-Melia) considerata di età cretacica (Papadoupolos,1982)

## EVOLUZIONE DELL'AREA RODOPICA ORIENTALE.

Alla fine del Cretaceo - Paleocene inferiore l'area dei Rodopi meridionali è interessata da piegamenti e sovrascorrimenti, come conseguenza di un processo di collisione che vede coinvolto il microcontinente pelagoniano (Innocenti et al., 1994,Ricou et al., 1998) in seguito alla chiusura dell'oceano vardariano in subduzione verso nord. Alternativamente la subduzione verso nord sotto il margine europeo dell'oceano Tetideo (Paleothetis) crea un complesso accrezionario in profondità con deformazione e metatorfismo delle unità coinvolte (Barr et al.,1999) La fase collisionale del Cretaceo - Paleocene inferiore produce un rapido sollevamento con l'esumazione dei più profondi livelli metamorfici (Zagorchev,2004). Durante il Paleogene l'intera area del MR è sottoposta a processi di sollevamento, estensione e magmatismo. Nel Paleocene - Eocene inferiore, alla fase di sollevamento principale segue una fase estensionale, che determina la formazione di locali bacini riempiti da depositi tipo flysch (Zagorchev,1998b). E'comunque a partire dall'Eocene medio (Luteziano) che l'intera parte orientale (Tracia) dei Rodopi subisce un esteso collasso estensionale che interessa l'intera area. Si formano spessi depositi trasgressivi sul basamento metamorfico rappresentati inizialmente da conglomerati seguiti da arenarie e da depositi contenenti carbone .Alla fine del Luteziano una fase di sollevamento interrompe la deposizione continentale . E' a partire dal Priaboniano che la sedimentazione su importanti settori del Massiccio Rodopico assume un carattere marino, prima con la formazione di depositi calcarei di acque basse contenenti coralli, alghe e foraminiferi, per poi proseguire, con l'approfondimento dei bacini, in depositi clastici tipo flysch. Le variazioni in spessore dei depositi clastici è notevole e legata alla limitata dimensione degli stessi e dalla variabilità dei processi estensionali da zona a zona. Si va da poche decine di metri, fino a spessori superiori ai duemila metri. All'inizio dell'Oligocene tutta l'area rodopica è nuovamente sottoposta ad un sollevamento. Si formano di nuovo sporadici depositi carbonatici di acque basse contenenti coralli ed alghe. In Tracia, l'Oligocene è generalmente rappresentato da depositi clastici sabbiosi, argillosi continentali (fluviali e lacustri) talvolta marini di acque basse. Depositi di flysch oligocenici continuano a depositarsi nella parte meridionale, nell'area egea . Essi sono ben rappresentati nell'isola di Limnos dove affiora sia la porzione dell'Eocene superiore, contenente olistoliti di calcari nummulitici, sia una spessa successione di flysch oligocenici che chiudono con deposito di conglomerati fluviali (Innocenti et al., 1994). Questo periodo di estensione è stato accompagnato da un breve periodo compressionale alla fine dell'Oligocene in Tracia, e nel Miocene nell'area egea (Innocenti et al., 1994, Burchfiel et al 2000, Turgut & Eseller, 2000) .

L'evoluzione tettonico sedimentaria dell'area rodopica orientale è accompagnata dallo sviluppo di un arco magmatico orogenico che borda tutto il margine continentale europeo. Quest' arco si sviluppa con continuità per tutta la penisola balcanica fino all'Anatolia occidentale per una lunghezza di oltre duemila Km (Yanev et al 1998). L'inizio di tale attività avviene nell'Eocene medio superiore. Nei Rodopi i primi prodotti vulcanici di tipo orogenico sono datati a 37 Ma con un progressivo ringiovanimento verso Sud fino al Miocene medio (ca.15 m.a. nello Egeo centrale ). Le vulcaniti predominanti sono le rioliti (30-40%), generalmente rappresentate da prodotti piroclastici, seguite da lave andesitiche (30-35%) e da daciti (15-20%), sia sottoforma di piroclastiti, che di lave. I prodotti basici sono scarsi ed indicativi di un vulcanismo sviluppatosi su una spessa crosta continentale (Yanev et al.,1998).

Nella parte greca dell'area rodopica il vulcanismo si è sviluppato essenzialmente durante l'Oligocene (Innocenti et al.,1984) ed è accompagnato dalla messa in posto di un belt intrusivo ( Del Moro et al.,1988).

Uno studio a grande scala delle successioni sedimentarie dei Rodopi centro-orientali e meridionali, combinato con le analisi petrografiche, la caratterizzazione delle mode detritiche, l'analisi degli elementi maggiori e in traccia e la loro elaborazione attraverso tecniche di statistica multivariata, ha permesso la descrizione delle complesse relazioni tra la sedimentazione clastica e l'evoluzione paleotettonica dell'area Circum-Rodopica. In particolare, è stata documantata un'evoluzione spaziale e temporale delle successioni sedimentarie che prevede, a larga la scala, l'impostarsi di una sedimentazione di ambiente continentale che evolve più o meno gradualmente ad ambienti marini e marino-profondi. Le successioni torbiditiche comprendono localmente livelli vulcanoclastici di differente natura e composizione messi in posto dal Priaboniano fino all'Oligocene superiore. In seguito all'analisi petrografica sono state determinate tre petrofacies: a) quarzolitica ($Qt_{67}F_{15}$ $L_{18}$ , Eocene medio-superiore, successioni di ambiente continentale); b) quarzoso – feldspatica ($Qt_{48}$ $F_{46}$ $L_{6}$, Eocene superiore – Oligocene, succesioni di ambiente marino-profondo); c) vulcanoclastica ($Qt$ $_{9}F_{35}$ $L_{56}$, Eocene superiore – Oligocene), legata a sedimentazione sin- e inter- eruttiva.

Le areniti appartenenti alla petrofacies quarzolitica riflettono una provenienza dall'Unità Tettonica Superiore (UTU), o Complesso Variegato, i quali includono frammenti di complessi ofiolitici. Questi, si rinvengono esclusivamente nelle areniti continentali dei Rodopi centro-orientali. I campioni dei Rodopi meridionali riflettono una provenienza dalla medesima unità tettonica e localmente dalla copertura epimetamorfica della cintura Circum-Rhodopica individuata nell'Unità di Makri.

Le areniti della petrofacies quarzosofeldspatica riflettono una provenienza dall'Unità Tettonica Inferiore, o Complesso gneissico-migmatitico, testimoniato dalla presenza di frammenti litici affini. In particolare, si rinvengono frammenti di roccia tipici di questa unità, come gli scisti ad epidoto, derivanti da metamorfismo retrogrado in facies scisti verdi, ampiamente documentato in letteratura (es. Patras et al., 1989).

Le areniti della petrofacies vulcanoclastica riflettono una provenienza da vulcanismo basico-intermedio, per quanto riguarda l'area dei Rodopi centro-orientali, e intermedio acido per i Rodopi meridionali. In particolare, è stata documentata una la prevalenza da parte di prodotti andesitici e subordinatamente basaltico-andesitici per la parte bulgara, e andesitico-dacitica per quella greca.

L'approccio geochimico ha permesso di documentare in modo accurato la limitata azione da parte di processi di alterazione chimica sulle aree sorgenti. In aggiunta è stato documentato, per le areniti della successione di Adira, nei Rodopi meridionali, degli effetti di metasomatismo da parte del potassio nella frazione argillosa.

I rapporti Zr/Sc *vs.* Th/Sc (McLennan et al., 1993) e Cr *vs.* Cr/Ni (Von Eynatten, 2003) hanno confermato, in accordo con l'analisi petrografica, che le areniti studiate non presentano evidenze di riciclo sedimentario.

L'elaborazione dei dati geochimici, attraverso tecniche di statistica multivariata, si è rivelata particolarmente utile nel fornire indicazioni di provenienza. In particolare, attraverso l'individuazione di associazioni da parte degli elementi maggiori e in traccia, ha permesso di identificare i segnali di provenienza e gli apporti detritici che hanno determinato particolari composizioni.

Per le areniti della petrofacies quarzolitica è stata documentata un'evoluzione dell'apporto detritico da aree sorgenti mafiche ad aree sorgenti felsiche. La composizione della petrofacies quarzosofeldspatiche ha evidenziato un'evoluzione inversa, suggerendo il rimaneggiamento e l'erosione delle porzioni superiori delle successioni continentali (provenienza da aree sorgenti felsiche) e successivamente delle porzioni inferiori (provenienza da aree sorgenti mafiche). L'elaborazione dei dati composizionali delle areniti vulcanoclastiche ha contribuito in modo significativo alla separazione per area di tali campioni, i quali riflettono caratteristiche di provenienza tipiche di un vulcanismo andesitico-dacitico per i Rodopi meridionali e andesitico – basalto-andesitico per i Rodopi centro-orientali.

Tale lavoro ha permesso quindi di ricostruire l'*unroofing history* dell'area orogenica Rodopica. I dati composizionali hanno evidenziato come l'inizio della sedimentazione rifletta una provenienza dal Complesso Variegato (o UTU, Unità Tettonica Superiore), o altrimenti detto complesso ultramafico. Il protrarsi del sollevamento ha comportato l'emersione, e quindi l'erosione, delle porzioni crostali più profonde, rappresentate dal Complesso gneissico-migmatitico (o LTU, Unità tettonica inferiore) formato da gneiss, migmatiti, metagraniti, di composizione più acida. Le osservazioni stratigrafiche, combinate con quelle petrografiche-geochimiche hanno documentato, a partire dall'Eocene superiore (Priaboniano) fino alla fine dell'Oligocene, la presenza di diversi edifici vulcanici, che hanno dato luogo a fenomeni di vulcanismo con diverse composizioni, caratterizzate e documentate attraverso le analisi sopra descritte.

# 1. INTRODUCTION

Sedimentary rocks are our principal sources of information concerning past condition on Earth's surface. Provenance analysis includes all inquiry that would aid in reconstructing the lithospheric history of our planet.

Clastic rocks may preserve detritus from orogenic settings at present hided by the tectonic overprint, dismemberment or erosion. In certain conditions the composition of clastic materials provides the only available evidence to the composition of strongly eroded source rocks, and for this reason represent a powerful tool in palaeogeologic reconstruction.

With the advent of plate tectonic theory has been noted that the global distribution of rock types could be explained in terms of tectonic settings. In the early 1970s Dickinson, with his group, related the framework petrography of sandstones to the plate tectonic setting of the rocks from which they derived. The role of sandstone petrology is fundamental in reconstructing the history of the Earth's crust and his understanding as an integrated system.

Sediment provenance studies, at present, include the interpretation of the processes generating the parent rocks and responsible of their emplacement.

Zuffa (1984), Morton (1989) and Johnsson (1993) introduced and developed the importance of understanding the control exerted by processes modifying sediment composition prior and following deposition.  These processes are physical and chemical weathering and erosion, in turn influenced by climate and relief of source area, fractionation and mixing during transport, recycling, burial diagenesis and consequent uplift. Erosion and sedimentation are essentially partitioning processes whereby the components of the source rock are differentially preserved. If the materials eroded from a group of source rocks were in physical and chemical equilibrium, then their proportions in the resulting sediment would be dictated merely by their abundance in the source rocks and by hydrodynamic sorting effects operating during transport and deposition (Johnsson 1993). Mineral phases differ in chemical and physical stability and consequently are affected by weathering processes in different ways.

In relatively recent time geochemical approaches to provenance studies demonstrated to be a powerful methodology that amplifies the provenance signals hided in sedimentary rocks.

It is widely accepted that the use of immobile elements are transferred in similar proportion throughout the sedimentary processes from parental rocks into clastic deposits (Taylor and McLennan, 1985; Condie, 1991). The geochemical approach is particularly useful in characterizing the sedimentary provenance, particularly in determining the terrane type and identification, the provenance age and crust – mantle character. Concerning the description of sedimentary processes, as weathering, sorting and sedimentary recycling, geochemical approach perfectly integrates information given by petrographic approach, except for diagenesis overprint. Here is supported the concept that the integration of geochemical and petrographic approaches is indispensable in provenance analysis.

A multidisciplinary approach has been used in this thesis in order to characterize the provenance of analysed sandstones which primarily consisted of modal analysis of arenites; geochemistry of major and trace elements (XRF) of arenites; statistical evaluation of geochemical data.

This work focuses on clastic sedimentation developed during the sequential history of an orogenic system, in the eastern Mediterranean Region. The aim is to produce and evaluate a large quantity of compositional data, both, petrographic and geochemical and to detail the changing detrital modes and geochemical trends reflecting the unroofing history of the orogenic terranes of the Rhodope Massif.

The onset of a volcanic activity during orogenic processes makes this area a perfect laboratory to study the relationship between tectonic setting, volcanic arc development and sedimentary response.

The lack of sedimentary studies in the whole Rhodope area constituted a disadvantage at the beginning. For the aim of this work has been necessary to use a stratigraphic and sedimentological approach in order to understand the development of sub-basins in the area and the relationship between tectonic and sedimentation. The presence of regional marker, as carbonate reef, has been helpful at the beginning, but the attempt to date them, here at Università della Calabria, brought to a new perception of the above mentioned relationship.

The statistical evaluation of geochemical data through the compositional data analysis technique, revealed to be particularly useful in reconstructing the provenance history of Eocene to Oligocene Rhodope sandstones.

## 2. THE GEODYNAMIC EVOLUTION OF AEGEAN AREA

### *2.1 Geodynamic setting of the southern European margin*

The Balkan and Hellenic peninsula is characterized by an articulated geological architecture generated by pre.-Cambrian, Cadomian, Hercynian, Cimmerian and Alpine s.s. tectonic movements. The present setting is the result of an intricate Alpine evolution in which crustal and ocenic elements reacted to the progressive convergence of the African Plate towards the european continent.

The multiple elements between these two continental blocks originated various isopic zones (fig.1):

*Moesian Platform(fig. 1):* gemorphologically it represents a flat zone covered by loess Quaternary deposits. It includes 4 – 5 km of pratically undeformed shallow marine Mesozoic successions lying unconformably on a weakly folded Paleozoic basement and buried beneath Paleogene, Neogene and Quaternary deposits. Major unconformities drilled at the base of the Triassic, Jurassic, Upper Cretaceous and Eocene record the main compressional events within the Alpine thrust belt (Transmed transect VII)

*External Balkan:* a transition zone between the Balkan Massif and the Moesian Platform, weakly deformed and with european type sedimentary facies. In the eastern part of the External Balkan Triassic and Jurassic rocks have been deeply buries below Cretaceous to Paleogene deposits.

*The Balkan s.s.(fig.1):* characterized by northward vergent thrust and folds developed starting from the Eocene. It is characterized by a Mesozoic to early Tertiary flysch and molasse successions.

*The Srednogorie zone (fig.1):* is a segment of a late Cretaceous magmatic belt extending from Romania through Yugoslavia, Bulgaria into Turkey. This belt has been interpreted by Boccaletti et al. (1974) Transmed transect VII) as the remnant of a volcanic Island arc related to the subduction of the Tethyan ocean underneath the Eurasian margin. Is considered as an *intra – arc* sedimentary basin of the coeval intracontinetal magmatic arc. The Alpine basament has been interested by faulting processes during the upper Cretacous (Senonian) after a period in which was emerged, during lower Cretaceous (Gočev, 1970). During the upper Cretaceous in the western and central part of this area an intense magmatic activity has developed, generating a thick volcanosedimentary successions and multiple intrusive bodies of Island arc signatures, while in the north-eastern sector the volcanic deposits are interlayerd with the Cenomanian – Turonian sediments (Kanchev, 1966; Gočev, 1970). The andesite products can be found in the whole Srednogorie area, while the shoshonitic products developed successively in eastern sector.

In the western and eastern part, the volcanic products lies on the Turonian molassic type sediments (quartzite, sandstones alternating with marls) or above the red and grey Senonian marls. Sedimentation in the Srednogorie zone is probably migrated from E to W through time, probably due to the basinal spreading above an heterogenous and strongly fragmentated basament. In the eastern sector the Cenomanian transgressive sedimentation starts in the southern part (Istrandja) and subsequently in the northern part.

The first deformative Cretaceous event developed locally and correspond to the sub-Hercynian phase (Bončev et al., 1944; Kostadinov, 1971). The southern boundary with the Morava – Rhodope zone is a complex system of thrust and normal faults with uncertain ages and relationships.

*The Morava – Rhodope zone (fig.1):* includes seven tectonic units: Morava, Ograzhden, Strouma, Pirin –Pangeon, Rila – Rhodope, East Rhodope and Makri.

All together are grouped in a superunit on the base of the following common features: widely exposed high grade metamorphic basement complexes; occurrence of Paleozoic, late Cretaceous and Palaeogene intrusive bodies of different size; development of isolated Paleogene basins with continental and shallow marine sediments associated with dominantly acid and intermediate volcanic rocks; main mid - Creataceous compressional deformations followed by late Cretaceous – Tertiary extensions; thick continental crust (50 – 52 km) in the central part of the zone, thinning to 34 – 37 km in SE – NW direction. This unit will be described in detail in chapter 3.

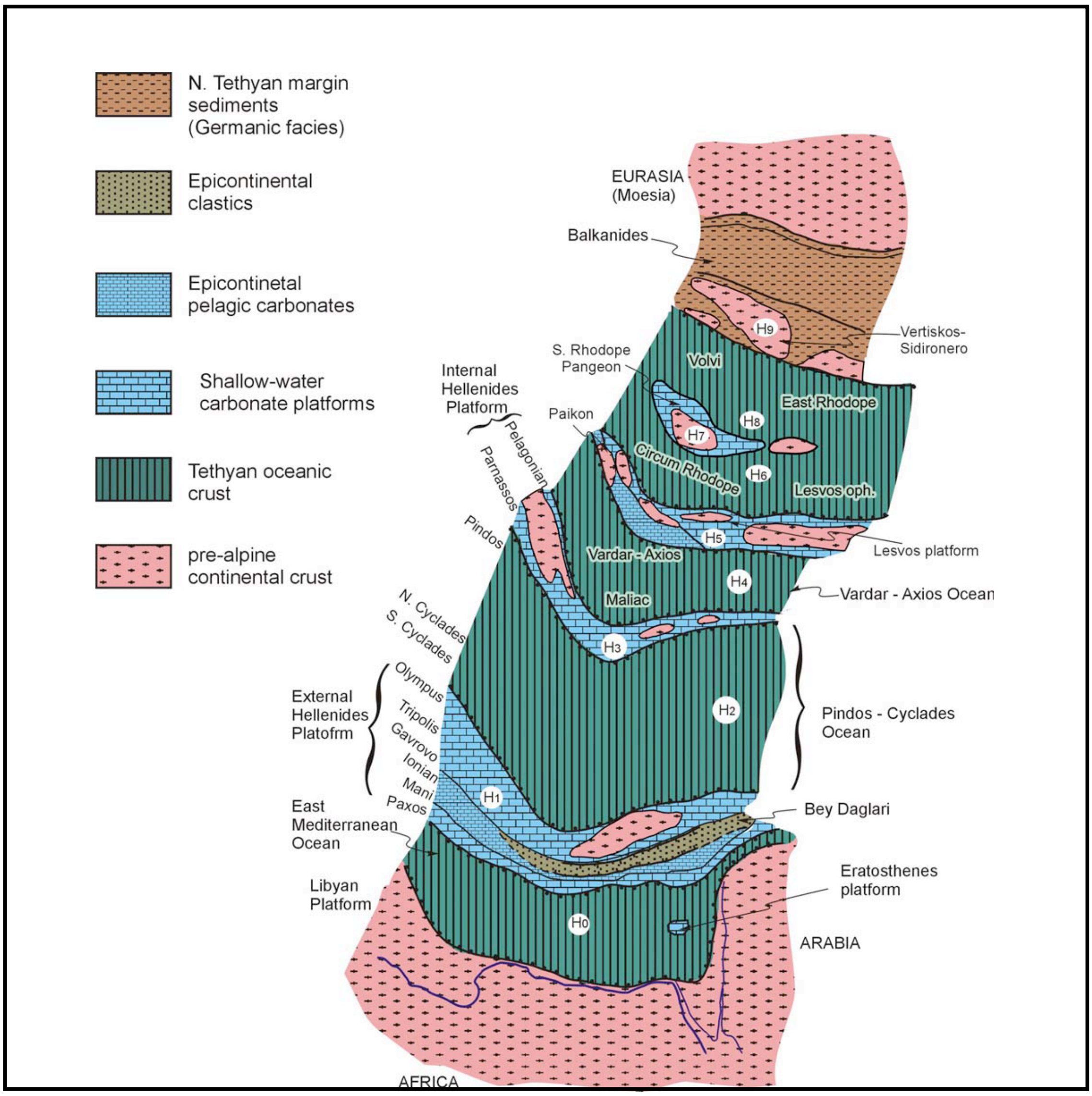



Fig. 1. Main geo-tectonic structures of Eastern M;editerrannean

## 2.2. *Relationship between magmatic activity and geodynamic processes in the Aegean area.*

After the main collisional phase, between the end of Cretacous and lower Eocene, the Aegean area has been interested by an intense magmatism, which generated products showing a wide petrology variation (Innocenti et al., 1981)(fig.2).

This area represents the ideal place to verify the relationship between volcanism and geodynamic processes in continental collision belts. The beginningn of his complex magmatic history could be placed at the end of the Eocene and lasted until the present day. The collision between Africa and Europe verified between irregular continental borders, originating margin fragmentation and subsequent formation of a mosaic of microplates with relative movements (MacKenzie, 1972, 1977, 1978, Dewey and Sengör, 1979).

The orogenic volcanic activity in the Aegean area generated two spatially and temporarily distinct belts. The ancient is located in the Rhodope Massif, which reached the climax between upper Oligocene and lower Miocene. The second belt, younger in age, is located on a narrow belt in southern Aegean sea, where represent a volcanic front developed during Pliocene and still active (Fytikas, 1976, 1979). The first volcanism developed along WNW-ESE direction in Bulgaria, Western Anatolia and Central Aegean sea, with ancient products placed in Rhodope Massif and turkish Thrace (Fytikas et al., 1982). From a compositional point of view, volcanic products belong to the calc-alkaline series, dominantly represented by andesites and dacites, and minor rhyolites and basalts (fig.2). Rare potassic and ultra-potassic products can be found in Bulgaria (Oligocene) and in western Anatolia, particularly in middle Miocene series (ca. 15-14 Ma, Yanev et al., 1998, Innocenti et al., 2005).

During Miocene verifies the southward migration of the volcanic activity (Fytikas et al., 1979) as reflected by gradual variations of erupted products compositions.

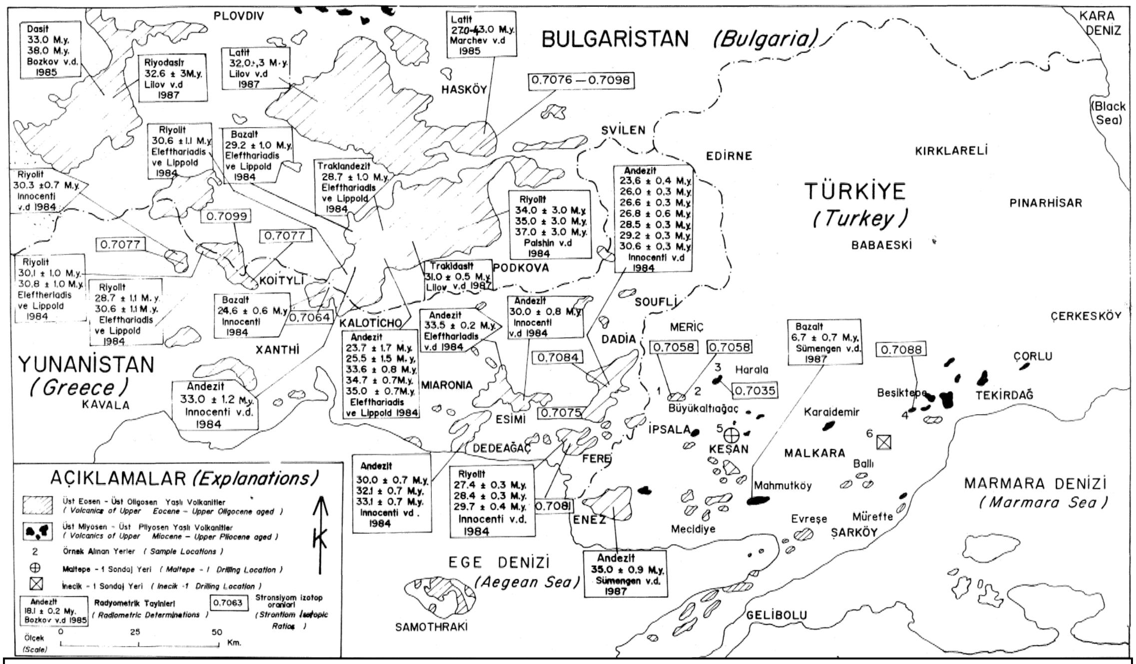



Fig.2 Composition, age, and location of volcanic activity development in north Aegean area,

Ancient products are represented by products related to the calc-alkaline series with $K_2O$ content typical of orogenic series erupted on thick continental margins. More recent products shows increments of $K_2O$ content, with frequent shoshonitic manifestations, typical of the end of volcanic activity (Limnos, Lesbos and western Anatolia) (Innocenti et al., 1982).

The increment in alkalinity in volcanic products is probably related to post collisional phase, when the subducted oceanic lithosphere has been affected by an increment of inclination nearing gradually to a vertical position. As result of the increment of the subduction angle a southward migration of volcanism developed accompanied by a compositional variation, function of the subducted lithosphere (Innnocenti et al., 1982). After the post - collisional phase, the displacement of the subduction to the southern sector, and the gravity forces determined the break-up of subducted lithosphere. The lateral pressure exerted by Anatolia microplate is responsible of the onset of a new subtactive phase in southern Aegean leading to a structural reassessment of the area. Consequently to this new subduction phase a new volcanic arc develops during Pliocene and still active at present day (Ellenic volcanic arc). This arc is characterized by the occurrence of products forming typical calc-alkaline phases, which show a continuous evolution from basalts to rhyolites. The most represented products consist of andesites and dacites, with basalts constituting the 25% of erupted products (Fytikas et al., 1982). From a petrological and geochemical point of view the southern arc is homogenous, even if there are important variation in eruptive styles and magmatic activity.

The development of volcanic activity is strongly connected to the proximity of geo-tectonic lineament as testified by the displacement of eruptive centres along the deformation belt between Anatolian and Aegean plates. Differences in distribution of volcanism on the Aegean plate could be interpreted basing on discontinuous lithospheric deformation processes. In fact, a rigid-plastic behaviour consequent to continental collision, should be correlated with diffuse volcanism in correspondence of thinned central Aegean area, where the volcanism is absent.

# 3. THE RHODOPE MASSIF

## 3.1 Geodynamic evolution of the Rhodope Massif

The history of the Rhodope Massif can be placed at Triassic – Jurassic boundary, when north – northeast directed subduction of Tethyan oceanic crust progressed beneath the southern margin of Eurasian continent. (fig.1, 2). A proportion of the subducted components were underplated or subcreted beneath the prism at various depths, while the remainder were recycled into the mantle. Much of the material must have been taken down to depths of at least 30–80 km within the subduction zone prior to accretion, thus accounting for the earliest high pressure metamorphic assemblages, including the eclogitisation of a significant proportion of the mafic material (Barr et al., 1999). Blueschists have not been preserved intact due to later metamorphic re-equilibration, although banded epidote–amphibolite sequences within Southern Rhodope strongly resemble variably retrogressed blueschists exposed in the Cyclades, to the south (Barr et al.,1999). The continue of the northward subduction of the African margin has been responsible of the building of the accretionary prism at depth. Between Eocene – Oligocene. the formation of the accretionary complex resulted in the continual vertical uplift of the entire overlying accretionary sequence. The mechanism of subduction–accretion implies quasi-continuous migration of the subduction system oceanward (southwards in this case) through time, and in turn must imply southward encroachment of the zone of arc-related magmatism through the exhuming metamorphic complex (Barr et al., 1999). Between Oligocene and Miocene the Rhodope Massif reaches the final exhumation in an extentional regime.

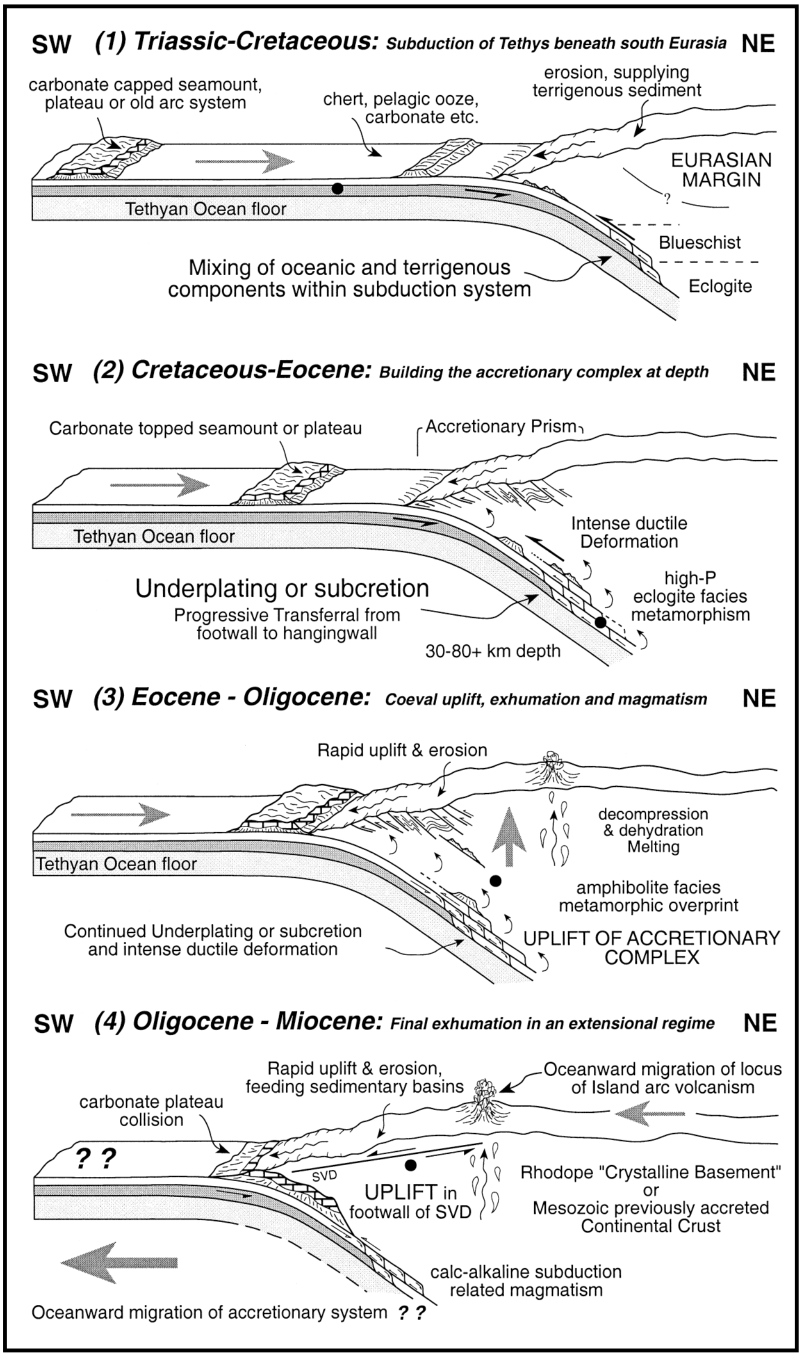



Fig.1. Diagram illustrating the evolutionary steps responsible of the accretionary processes of Rhodope Massif. 1) Beginning of the subduction of African plate underneath southern European margin; 2) building of the accretionary comple at depth; 3) Uplift of the accretonary complex and beginning of magmatism; 4) final exhumation and southward volcanic arc migration (from Barr et al., 1999)

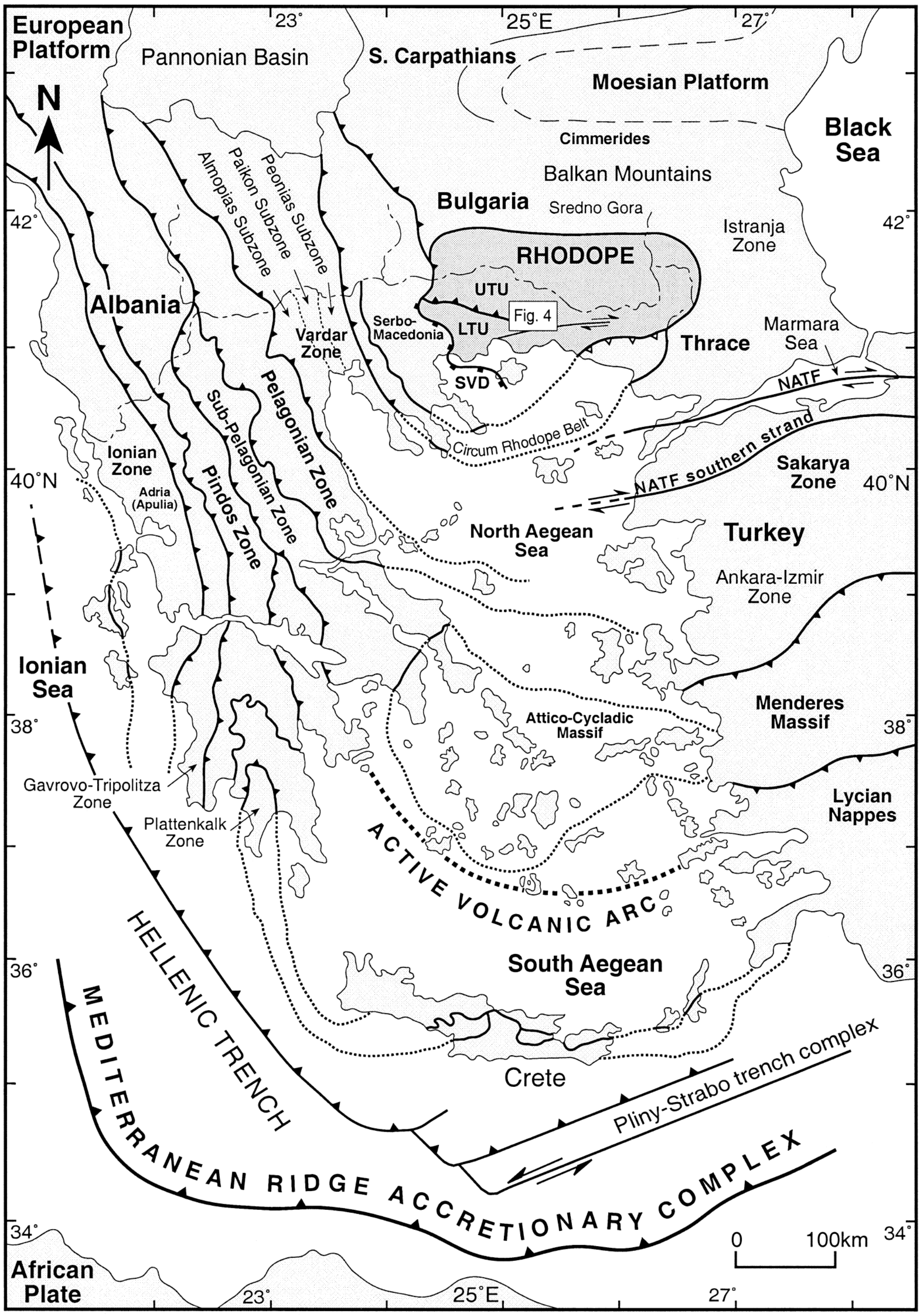



Fig. 2. The Aegean region, illustrating the position of Rhodope and the study area, with respect to the surrounding Dinaric and Hellenic 'Alpine' tectonic zones. UTUs Upper Tectonic Unit (Barr et al., 1999)

### 3.2 GEOLOGY OF RHODOPE MASSIF

The Rhodope Massif (RM) is bounded by the Vardar zone to the west, by the Aegean sea to the south and by the Maritza river to the north. On the eastern side, the Strimon valley is crossed by granites and high grade metamorphic rocks marking the limit between the Serbo-Macedonian Massif and the Rhodope Massif to the west (Dimitrevic et al., 1967, 1974) (fig.3). The RM is generally considered as part of the Alpine orogen, formed due to the convergence processes between african and european plates at the closure of Palaeothethys.

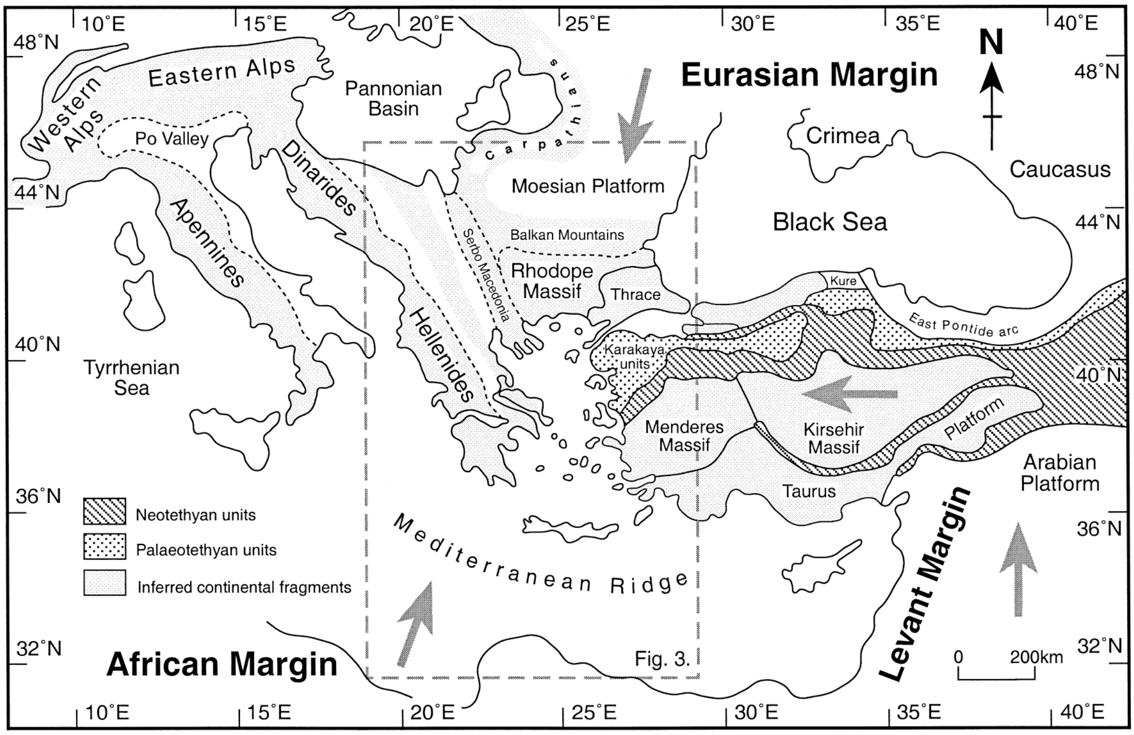



Fig.3 Map outlining the position of Rhodope in relation to the main continental fragments or massifs and accretionary units, associated with convergence between Africa and Eurasia. (Inferred continental fragments and Neotethyan and Palaeotethyan accretionary units are compiled from maps presented by Sengo¨r et al._1984., Robertson et al._1991.and Robertson et al._1996). Arrows represent directions of plate motion and dashed line marks area illustrated in Fig. 2.

The RM massif has been generally interpreted as a micro-continent formed during the break-up of the super continent Pangea. From Palaeozoic until the Mesozoic the northern edge of Paleotethys migrated northward merging with the european margin as described by Stampfli and Bore (2004) at the end of Paleozoic in correspondence of the Moesian platform.

Contemporarily to this event there is the opening of the Neotethys that created along the european margin, during Jurassic, relatively small oceanic basins as Pindos and Vardar (fig.2). The closure of the Tethys ocean, due to the northward convergence of the african plate will be the geodynamic element responsible of the RM evolution from the end of Cretaceous until Miocene.

Other hypothesys consider the RM as an hercynic or pre-cambrian continental fragment (Barr *et al.,*1999). These authors propose that the metamorphic associations are the result of a continuous transfer of oceanic and crustal material from the footwall to the hangingwall as consequence of the northward subduction of Paleothethys.

### *3.2.1 Geological framework of Circum-Rhodope belt*

Following Ricou et al. (1998), the Circum-Rhodope Belt can be distincted in function of two metamorphic complexes: the Pre-Rhodopic and the Rhodopic Supergroups. The first is constituted by continental crust, granitic in composition (migmatite, gneiss and meta-granites), which includes amalgamated bodies of mafic and ultramafic rocks. The second is formed by Pre-Cambrian products of continental arc origin (sedimentary sequences of flysch type, volcanic sequences and platform limestones). These Supergroups has been deformed during Cadomian and intruded by Paleozoic-Cretaceous granites. Ricou et al., (1998) proposed that Rhodope metamorphic complex formed as a consequence of detachment and upwelling of low-density material. To the other side, Mariolakos et al. (2004), asserted that the metamorphic complexes of Rhodope Massif formed during the accretion of crustal and mantle fragments, Paleozoic-Mesozoic in age, deformed by Alpine orogenesis.

In Southern Rhodopes (Greece), the Rhodope Massif consists of two tectonic units represented by the Pangaion Unit (tectonically in lower position) and the Sidironero Unit (tectonically in upper position). The Pangaion Unit consists of marbles, amphibolites, gneiss and mica-schists. The Sidironero Unit includes gneiss (rich in muscovite, biotite and augite), amphibolites, migmatites and anatectic granites.

In central part of Rhodope Massif three metamorphic events have been recognized (Liati, 1986; Mposkos et al., 1986a,b; Mposkos , 1989; Mopskos & Perdikatsis, 1989): a) an high pressure (ca. 15 kb) eclogitic event; b) a Barrowian type metamorphism (ca. 6-9 Kb and 550°); c) retrograde metamorphism of low pressure in green-schists facies. On the base of K/Ar dating (Liati, 1986) on eclogitic hornblende has been determined that the high pressure metamorphism occurred at 95 Ma, while the Barrowian metamorphism at 47 Ma. This event could be related to the shear phases developed during the convergence and interaction between African and European plates. Particularly should be connected with the shear system connected with the thrust of the Serbo-Macedonian Massif on the Rhodope Massif.

Patras et al. (1989), retain that the lower unit has been interested by low-medium grade metamorphism in green-schist facies, while the upper unit by two metamorphic events, one in amphibolitic facies and the other, of retrograde type, in green-schist facies.

In the area of Xanthi-Echinos, in Central Rhodopes, are exposed meta-sediments, represented by extremely micas rich gneiss, schists and quartzites. These are often associated with calc-silicate rocks, marbles and amphibolites. Marbles and calc-silicates rocks are often in contact with lenticular bodies of amphibolites. These marbles are characterized by boudinage and milonitic fabric and are often in alternation with mica-schists which mark the contact with the upper tectonic unit (Barr et al., 1999).

The metamorphic sequence includes gneiss, migmatites, amphibolite-epidote-rich and amphibolite-garnet rich, indicating an origin from a retrograde metamorphic phase in eclogitic facies. Quartz veins included in meta-pelites could be associated to the upward migration of water loss during for dehydratation of metamorphic rocks.

Crystalline metamorphic rocks are intruded by plutonic rocks, variable in composition, ranging from granites to gabbros passing through granodiorites, monodiorites, monzonites, covered by Tertiary sedimentary and volcanic rocks (Atzori et al., 1991).

## 3.3 The Paleozoic crystalline units of the Rhodope basement

### *3.3.1 The Gneiss-Migmatite Complex*

The Gneiss–Migmatite Complex (Kozhoukharov et al., 1988; Haydoutov et al., 2001) corresponds to the Continental Unit of Ricou et al. (1998) and structurally represents the deepest level in the metamorphic basement. Exposures are generally limited to windows within the cores of large-scale domal structures (Bonev, 2006).

From a tectono-stratigraphic point of view it represents the lower unit (LTU) and it's generally bordered on its top by extensional detachment faults and/or mylonitic shear zones. This unit is dominantly composed by a gneiss-migmatite series up to 6 km thick. The unit includes the Kessebir and Biala Reka metamorphic domes, both in Central Rhodope area (south Bulgaria) (Burg et al.,1996; Ricou et al., 1998; Bonev, 2002, 2006), and the Kardamos and Kechros complexes in Greece (Mposkos and Krohe, 2000; Krohe and Mposkos, 2002). The Gneiss-Migmatite complex is composed by orthogneisses underlain by porphyroclastic orthogneisses (metagranites) with megacrysts of K-feldspars (Bonev,2006). Orthogneisses are intercalated with migmatites and migmatitic gneisses, psammitic paragneisses, metapelites, and various amphibolite layers at different stratigraphic levels.

Rocks of that Complex have been analized using the U-Pb datation on zircons (Peytcheva and von Quadt, 1995; Arkadakskiy et al., 2000; Ovtcharova et al., 2003; Carrigan et al., 2003) and Rb-Sr (Mposkos and Wawrzenitz, 1995) giving an age of ca. 335 to 300 Ma, corresponding to the Hercynian orogenesis and indicating that the complex is attributable to a Variscan or older continental basement (Marchev et al., 2004).

In Central Rhodopes an eclogite facies metamorphism has been followed by amphibolite-facies conditions, and low pressure, low temperature retrogressive greenschist facies conditions (Macheva, 1998).

In Southern Rhodopes the LTU records an isothermal decompression during amphibolite facies overprint in migmatized gneiss (Mposkos and Liati, 1993; Mposkos, 1998).

The $^{40}Ar/Ar^{39}$ on mica (Bonev et al.,2006b; Marchev et al., 2003, 2004a) documents a 37-38 Ma cooling after amphibolite facies metamorphism, accompained by extentional exumation of the lower grade unit. Similare radiometric age have been obtained by Mposkos and Wawrenitz (1995) that evidenced a cooling – exumation history between 36 and 42 Ma suggesting that metamorphism events occurred before Middle Eocene, probably during Upper Cretaceous.

### *3.3.2 The Variegated Complex*

The Variegated Complex (Kozhoukharov et al., 1988; Haydoutov et al., 2001) corresponds to the Mixed Unit of Ricou et al. (1998) and to the Kimi Complex in Greece (Mposkos and Krohe, 2000; Krohe and Mposkos, 2002) and rapresents the Upper Tectonic Unit (UTU). Is generally dominated by non migmatized gneisses, amphibolites and marbles (Boz dag), metagabbros, meta-pelitic schists and rearely quartzite. The Variegated Formation (VF) shows flysch characteristics (Kozhoukharov, 1987) including an alternation of quartzites and metapsammites with metapelites and marbles locally up to 80 m thick. Small lenses and bodies of ultramafic rocks, such as peridotite, testifying the affinity with dismembered meta-ophiolite association (Khozhoukharova, 1984). Is characterized by the presence of orthoamphibolites generally occurring in layers alternating with sediments or as intrusive bodies intersecting with the ultramafic fragments of the ophiolite units (Haydoutov et al., 2001). The relationship between the orthoamphibolites and the ultramafic rocks has been observed in the Bela Reka antiform (Haydoutov et al., 2001) where the metabasites cross-cut the ultramafic bodies. The association of the high-grade unit with metabasic rocks supports the theory that the protoliths partially originated in a marginal basin-arc tectonic setting. Haydoutov demonstrated an Island-arc origin of the Variegated Formation, supported by the association of the sedimentary rocks that overlies the ophiolite complex, consisting of marine volcaniclastic turbidites, ash deposits and tuffs deposited in trench settings. The association of this sedimentary successions with boninitic and tholeiitic magmatites is typical of Island-arc settings (Haydoutov, 2004). In the Eastern Rhodopes, the Variegated Complex is tectonically overlain by phyllites, albite gneisses, marbles and greenschist-facies metamorphosed mafic and ultramafic igneous rocks of Jurassic to Early Cretaceous age (Marchev, 2005).

The Kimi complex ultramafic rocks in Greece testify the first ultra high pressure event (P > 26 Kbars; t > 900°C) (Mposkos and Kostopoulos,2001). The eclogite – granulite facies in Kimi complex decreased to ~10 Kbar and 600-650°C, in medium pressure conditions and consequently retrogressed to greenschist facies (Mposkos and Krohe,2000; Mposkos 2002)

SHRIMP dating of zircons from a gabbro in the Variegated Complex overlying the Biala Reka dome shows Neoproterozoic cores (570 Ma) overgrown by Variscan rims (~300 to 350 Ma; Carrigan et al., 2003), implying that these rocks, and perhaps even their amphibolite-facies metamorphism, are of Pre-Alpine age.

The Variegated complex includes intrusions of syn- to post-tectonic granites dated through the U-Pb zircon method and having an age of ca. 70 Ma (Marchev et al., 2004b).

The $^{40}Ar/Ar^{39}$ amphibole and muscovite ages, respectively, of 45 ± 2 Ma and 39 ± 1 Ma (Mukasa et al., 2003) bracket the cooling history from amphibolite- to greenschist-facies conditions (Bonev, 2006).

### *3.3.3 The Mesozoic unit*

Low-grade Mesozoic rocks are characteristics and concentrated in the Eastern Rhodopes tectono-stratigraphic unit8 (fig.4), and tectonically overlains both, the UTU (Gneiss-Migmatite Complex) and LTU (Variegated Complex) (Bonev, 2006).

These low-grade metamorphic rocks are commonly associated to the extentional phases into the Eastern Rhodope of the Circum-Rhodope Belt (Kauffman et al., 1976; Papanikolau, 1997). The age of this unit has been obtained by Bigazzi et al. (1989) and Tsikouras et al. (1990) dating through apatite fission tracks on magmatic rocks and using K/Ar on hornblende amphibole, and by Dimadis and Nikolov (1997) through fossils analysis. All this studies collocated the origin of this unit between 140 and 161 Ma, Middle Jurassic to Early Cretaceous. In

Bulgaria this unit consists of greenschists and phyllite at the base overlain by tholeiitic lava flows and metapyroclastic rocks. Bonev and Stampfli (2003) interpreted the Mesozoic unit as a Late Cretaceous island arc accretionary assemblage in the Tethyan domain, basing on their structural data and green schists and mafic lavas chemistry. In southern Rhodopes, low-grade Mesozoic unit is represented by the Makri Unit which is part of the *Circum – Rhodope belt* and comprises greenschist facies rocks of uncertain age (Paleozoic or Mesozoic) overlain by Jurassic black shales and upper Cretaceous sediments and volcanics (Boyanov et al., 1990). This unit is interpreted as a complex thrust slice emplaced over high grade metamorphic rocks as a result of mid- and late Cretaceous compressional events (Transmed transect VII).

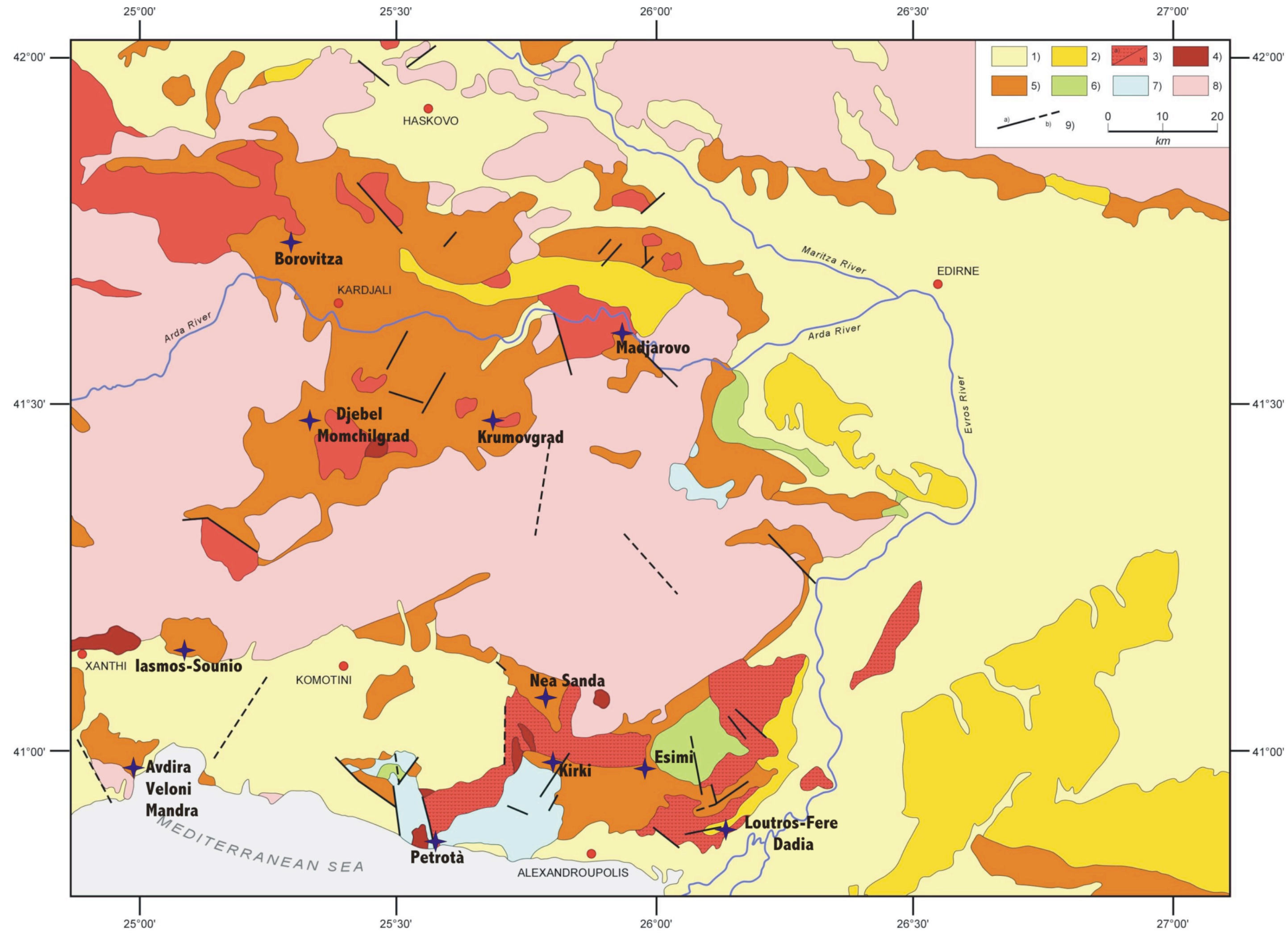



**Fig.4** Simplified geological map showing sampled areas. 1) Miocene-Quaternary marine and continental clastic deposits; 2) Oligocene marine and continental clastic deposits; 3) a: lower Oligocene and b: upper Eocene calc-alkaline lavas and pyroclastic rocks; 4) Oligocene intrusive rocks; 5)Upper Eocene continental clastic deposits, reef limestones and flysch successions; 6) Jurassic-Cretaceous epi-metamorphic and mafic-ultramafic magmatic rocks; 7) Triassic-Jurassic sedimentary and epi-metamorphic rocks (schists, marbles and intrusive rocks; 8)Metamorphic and magmatic rocks of Rhodope Massif; 9) a: faults; b: inferred faults

### 3.4 The Tertiary volcanism in Rhodope area

The Rhodope area involves one of the most developed sectors of the Serbian – Macedonian – Rhodopean magmatic belt. The development of the volcanic activity in this area is related to the main phase of the Eocene – Oligocene continental collision between Europe and the Apulian microplate. During Tertiary the area has been characterized by the onset of a collisional prism and afterwards by a post collisional collapse responsible of the formation of a fault controlled sedimentary basins with associated calc-alkaline to high-K calc-alkaline to shoshonitic magmatism with Priabonian to Miocene age. The development of the volcanic activity in this area is related to the main phase of the Eocene – Oligocene continental collision between Europe and the Apulian microplate. This activity lasted until the end of the Oligocene along the Serbo – Macedonian – Rhodope Massif. The Eocene – Oligocene magmatism developed after an important phase of thickening and uplift of the continental crust as testified by its present day crustal thickness reaching locally 50 – 55 km in the Rhodopian region (Yanev et al., 1998). In the study area there is a gap of 30 – 35 ma between the end of the volcanic activity of the Cretaceous volcanism of the Srednogorie area and the Priabonian - Oligocene volcanism (Yanev et al., 1998). Composition of magmatic products tends to be extremely different in the area demonstrating a strong dependance from the crustal thickness.

The volcanic activity includes considerable volumes of intermediate and acid volcanic and plutonic rocks, and subordinate basaltic and lamprophyric rocks.

In the Eastern Rhodope magmatic zone, magmatic rocks show the widest $SiO_2$ variations and cover the full range of rocks, from basic to acid (Marchev et al., 1998).Silica range of volcanic products of Southern Rhodopes is limited from basaltic andesite to rhyolite, with andesite as major rock type (Innocenti et al., 1984).

The occurrence of volcanic activity in the studied area could be summarized in three main phases, starting from upper Eocene (Priabonian) and lasting until the upper Oligocene (Chattian).

*Priabonian volcanism (37 – 35 Ma)*

The volcanic activity begins in southern Bulgaria at 37 Ma in the central and generally indicates a K-alkaline affinity (Ivanov, 1963; Marchev, 1985) where latites are predominant, with minor shoshonites and shoshonitic basalts representing the end members of the volcanic activity of this phase (fig.5). The central part is characterized by the presence of two volcanoes: the Paleo – Zvedzel and the Irantepe. The products of this area generally belong to the high – K calcalkaline association and are mainly represented by andesitic rocks and acid domes (Momchilgrad – Arda area).

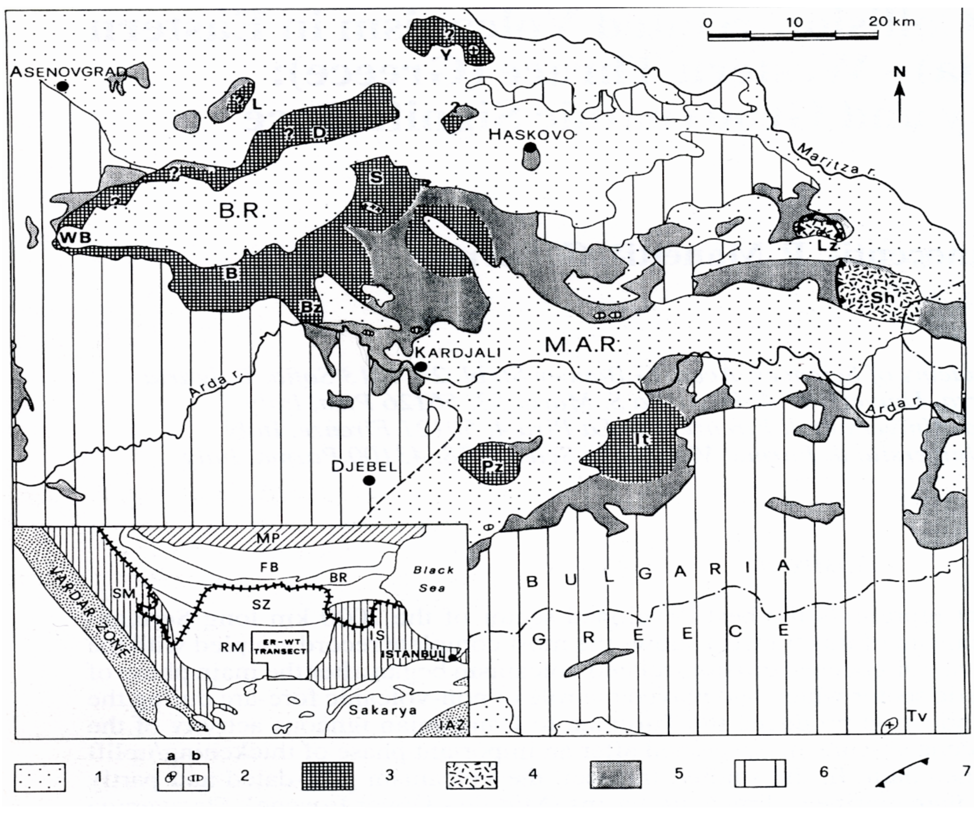



Fig.5 Priabonian (I phase: 37-35 Ma). 1) Products of later phases and Neogene-Quaternay deposits; 2a) Intrusives; 2b) volcanic bodies out of scale; 3) Volcanoes (mainly intermediate to basic) B Bezvodno; Bz,Bezdiven,; D, Dragonia; It, Iran Tepe; L, Lenovo; Pz, Paleo Zvedzel; S, Sarnitza; WB, western Borovitza; Y, Yabalkovo.; 4) Acid volcanic (Lz, Lozen Volcano; Sh, Sheinovetz caldera.; 5) Priabonian sediments and volcano-sedimentary deposits; 6) Crystalline basement; 7) Caldera rims (from Yanev et al., 1998)

*Lower Oligocene phases (34–32 / 31–30 Ma)*

This phase consists of two parts characterized by the increasing acidity of Central Rhodope products corresponding to a decreasing of the volcanic activity in its northern part and the beginning of it in Western Thrace (Yanev et al., 1998) (fig.5b). The firsts consist of ultrapotassic latites , high potassium andesites and ignimbrites deposits, variable in composition, from trachytes to trachydacites (Yanev et al., 1998). The final activity is represented by the occurrence of rhyolitic domes and lava flows. Between 33 and 32 Ma the volcanic activity began in Western Thrace (Yanev et al., 1998). Products generally consist of basaltic andesites to dacites; calc-alkaline and high-K calcaline andesite are the predominant products (Innocenti et al., 1984).

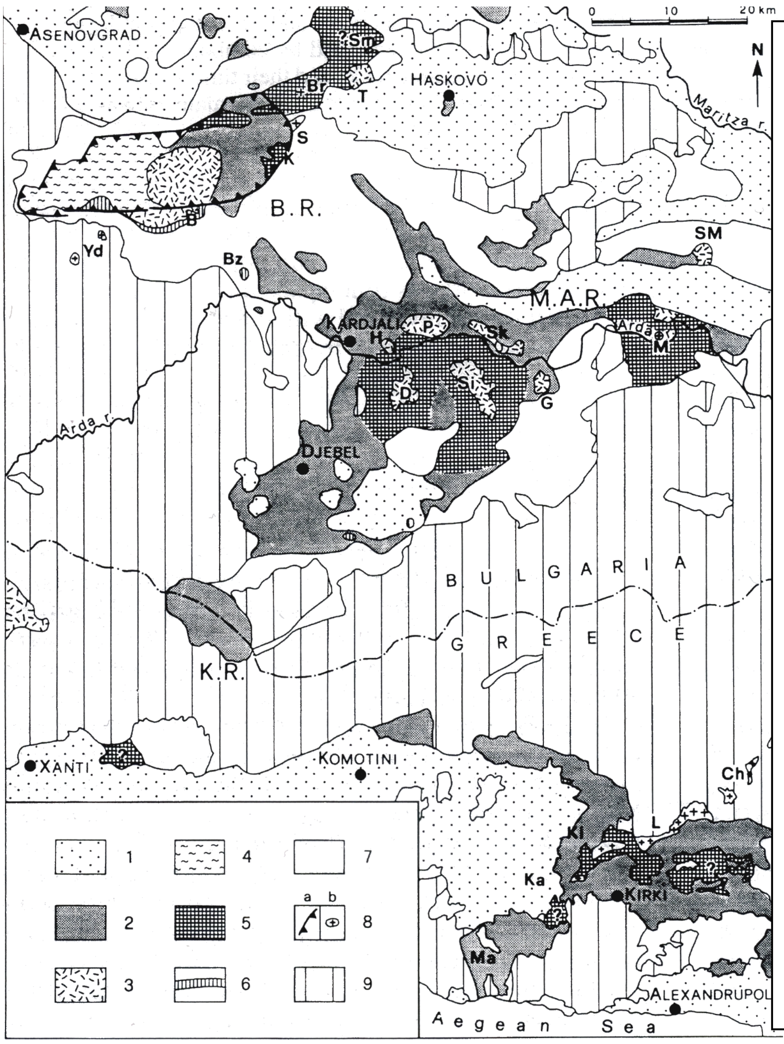



Fig5.b. Lower Oligocene (phase IIA: 34-32 Ma).

1) Products of later phases and Neogene-Quaternay deposits;

2)Pyroclastic and volcano-sedimentary deposits;

3) Acid volcanoes (D, Dambalack; G, Geren; H, Hissar; Si, St.Ilia; Sk, Studen Kuadenez; SM, Ste Marina; T, Tatarevo);

4) Welded ignimbrites;
5) Intermdiate to basic volcano-es (Br, Briastovo; K, Komouniga, M, Madjarovo; Sm, Susam);

6) Intermediate sills (B, Bevoz-dno; Bz, Bezdiven)
7) Priabonian sediments and volcano-sedimentary deposits;

8) a: caldera rims; b: intrusions (S, Sarnitza; Yd, Yolen-dere; Ch, Halasmata; Ki, Kirki; Ka, Kassitera; L, Leptokaria);

9) Crystalline basement
(from Yanev et al., 1998)

*Upper Oligocene phase (29-24 Ma)*

During this time dykes and subvolcanic bodies, mostly with a rhyolitic composition has been placed. The volcanic activity is mostly limited to Western Thrace, particularly in the Fere – Dadia region (fig) where pyroclastic flows and rhyolitic ignimbrites are the dominant products.

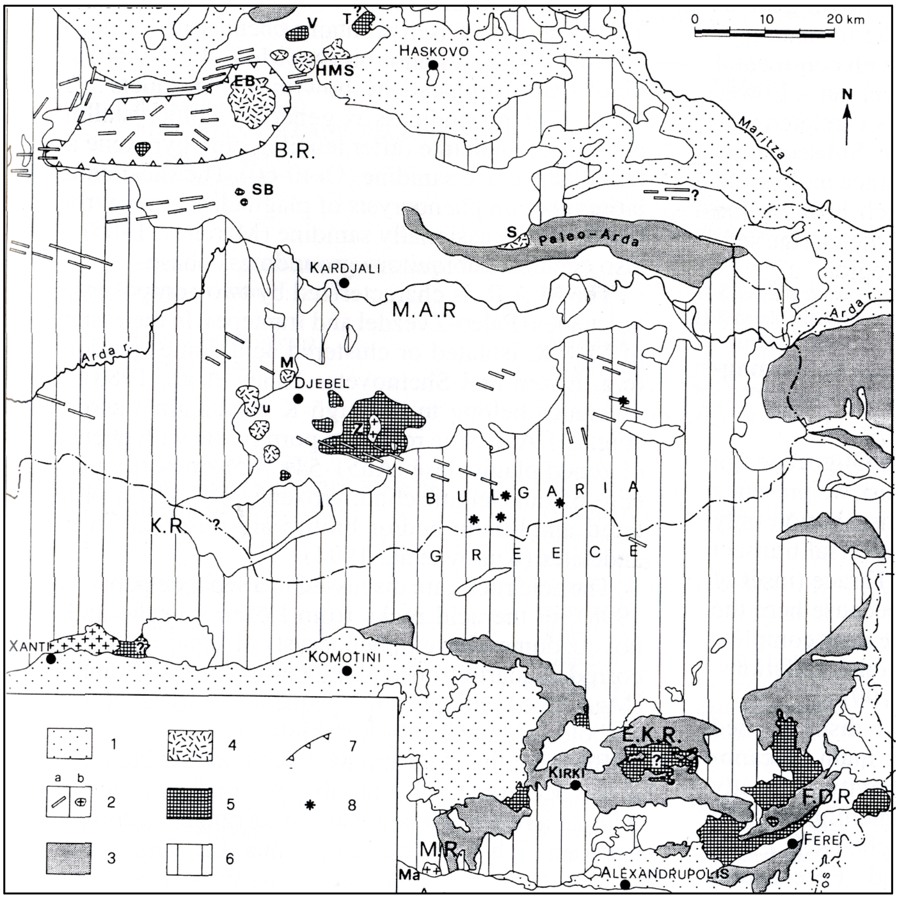



Fig.5c. Lower (Phase IIB: 31-30 Ma) – Upper Oligocene (Phase IIC: 29-24 Ma). 1) Neogene – Quaternary deposits; 2) IIC Phase: a, dikes, b, intrusions (Ma, Maronia); 3) Sediments and volcano – sedimentary deposits; 4) acid volcanoes (S, Silen-IIC phase- and dome clusters of IIB phase; EB, Eastern Borovitza; HMS, Haskovo mineral springs; U, Ustra; M, Mishekovo domes); 5) Intermediate to acid products (SB, south Borovitza; V, Voden; T, Tatarevo; Z, Zvedzel); 6) Crystalline basement; 7) Caldera rims; 8) Alkaline basalts and lamprophyres (from Yanev et al., 1998).

### *3.4.1 Central - Eastern Rhodopes volcanism*

The beginning of magmatic activity is placed during Priabonian at 37 Ma (Ivanov, 1963; Marchev, 1985). Products in the study area belongs to low-K, calcalkaline, high-k alkaline and shoshonitic series (Yanev et al., 1995). Latite-shoshonites and rhyodacites-rhyolites are dominant in Borovitsa are with minor basaltic and trachytic types and acid ignimbrites in its western part (Yanev & Bardintzeff, 1997). Zvedzel and Madjarovo volcanic area (fig.6) have similar $SiO_2$ range, but basic and intermediate types are more widespread.

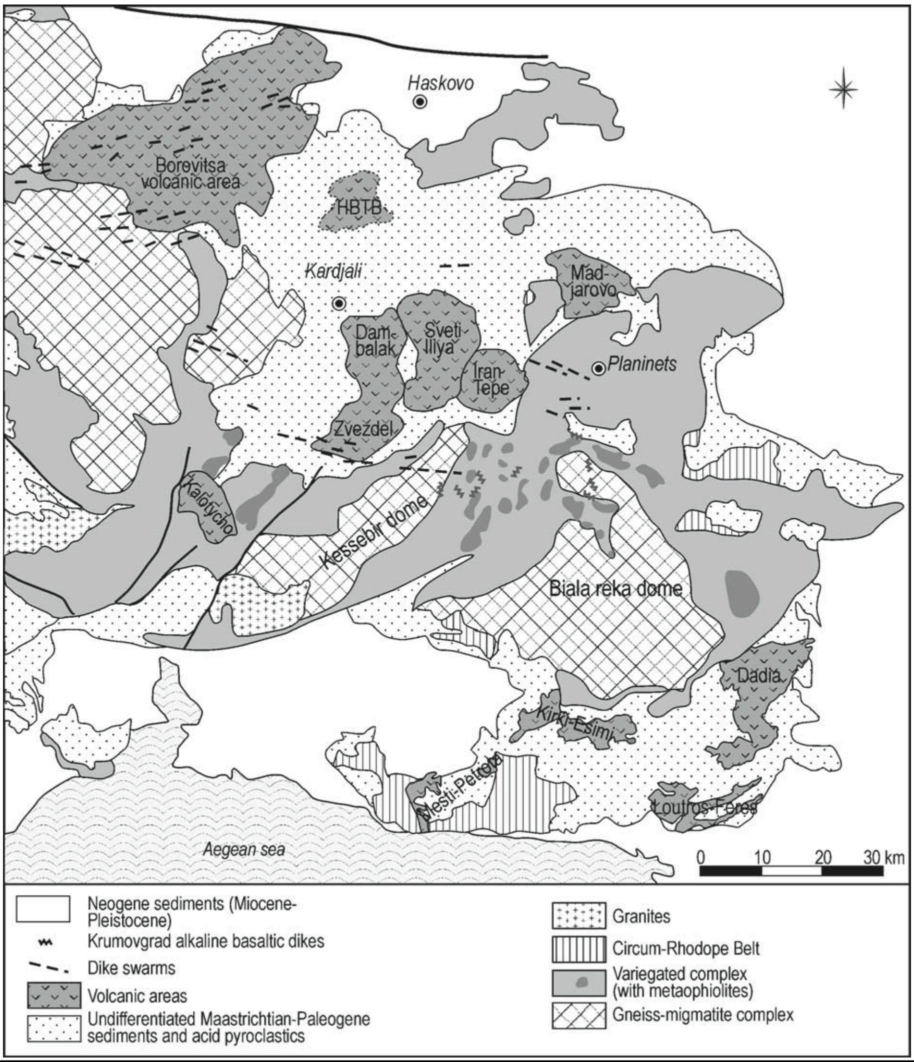



Fig.6. Geological sketch showing the two tectonic units (Variegated and Gneiss-Migmatite complexes) and the dislocation of volcanic areas (From Marchev et al., 2005).

*3.4.1.1. Temporal evolution and occurrence of acid products.*

The Paleogene acid volcanic activity is represented by four volcanic phases described and determined by Lilov et al. (1987) through K/Ar datation tecnique. One Priabonian (37-35 Ma) and three Lower Oligocene, usually recognized as I (34 Ma), II (32-33 Ma) and III (31-30 Ma), phases have been defined (Ivanov, 1960). This acid phases alternates with three other phases, intermediate in composition. The first two acid phases are rapresented by explosive products covering wide areas and for this reason used as tephtochronological markers (Yanev, 1998). The third acid phase is characterized by the presence of numerous dike swarms intersecting volcanic rocks and the cristalline basement (Yanev, 1998).

In the Momchilgrad area (fig.6) different products of differents phases occurs separately and indicates specific temporal migration of volcanic activity fron NE to SW (Yanev et al., 1983). The central volcanic group (Arda) is related to the I and II Oligocene phases while volcanism in Djebel group formed during the III phase.

In Borovitza area (fig.6) products forms a continuous succession with no evidence of migration of the volcanic activity. Volcanism begins during Priabonian with latite products and small sheets of acid tephra (Yanev, 1990).

*3.4.1.2 Evolution, occurrence and composition of intermediate products*

Intermediate volcanism specially occurs in the Momchilgrad-Arda volcanic region (MAVR). The activity in this area occurred for the whole period of time in which the volcanims taken place in East Rhodopes. Four principal volcanoes with intermediate products have been described (fig.6): Dambalak, Zvedzel, Sveti Ilija and Iran Tepe, the products of which are exposed in the whole area. Froma an evolutionary point of view first intermediate in composition products belongs to the Iran Tepe volcano, while second cycle products are found in the Sveti Ilija volcano and those of the third cycle in the Zvedzel volcanic rocks (Nedialkov and Pe-Piper, 1998). The record of felisc volcanic rocks belonging to the first and second cycle are essentially represented by pyroclastic and lava flows and domes (Yanev et al., 1983).

The Iran Tepe volcanic products mostly consist of andesitic pyroclastic rocks, lava flows and epiclastic rocks. This volcano rapresents the first occurrence of volcanic activity in the area, of Priabonian age (37-35 Ma), as determined by K-Ar dating (Lilov et al., 1987). Andesites of this area generally includes phenocrysts of zoned plagioclase, brown-reddish amphibole and rarely pyroxenes with a groundmass showing microlithic and hyaloplitic textures (Nedialkov et al., 1998)

Basic to intermediate volcanic rocks from the Sveti Ilija area rapresents the products of an elapsed volcanic evolution and ranges from basaltic-andesites to andesite and latite. K-Ar dating has determined a range between 31-23 Ma (Lilov et al., 1987). Rocks of this area are usually porphyritic with phenocryst of zoned plagioclases,sometime with biotite inclusions, augite, enstatite and rarely biotite and sanidine (in latites) (Nedialkov et al., 1998).

A wide compositional variability is characteristic for the Zvedzel volcanic area with products alternating from basalt to basaltic andesites, to andesites and trachyandesites sometimes intruded by differentiated plutons (monzogabbro, monzonite and granites) (Nedialkov, 1987). Volcanic products shows an age between 33 and 26.5 Ma (Lilov et al., 1987). Basaltic products are porphyritic with phenocrysts of zoned plagioclase, augite, enstatite and rarely olivine included in a hyaloplitic groundmass (Nedialkov et al., 1998). Andesitic products are porphyritic with phenocrysts of zoned plagioclase, augite, enstatite, amphibole and biotite ina trachytic to microlithic groundmass (Nedialkov et al., 1998).

Products having basaltic composition are located in the nearby of Krumovgrad and normally intrudes felsic pyroclastiv and volcano-sedimentary rocks of the first felsic volcanic event (Nedialkov et al., 1998). This products represents the end of the volcanic activity in the area (29-26.5 Ma). Basaltic bodies in the area shows abundant phenocrysts of zoned plagioclase, augite, enstatite in a glassy colorless – brownish groundmass suggesting tipically more felsic (colourless) or mafic (brownish) in composition (Nedialkov et al., 1998).

### *3.4.2 Southern Rhodopes volcanism*

Southern Rhodopes volcanic province (fig.6) generally includes two areas, one north of Xanthi town, known as the Kalotycho volcanics (Eleftheriadis and Lippold, 1984; Innocenti et al., 1984), and the other in western Thrace defined as the Evros volcanic rocks (EVR) (Eleftheriadis, 1989). For the aim of this work only the latters will be described. Basing on K/Ar datations three main volcanic phases have been described: 1) Lower Oligocene, ranging from 33.4 to 33.1 Ma.; 2) Upper Oligocene, from 32.2 to 25.4 Ma; 3) Lower Miocene, from 22.0 to 19.5 Ma. Rocks from EVR clearly shows characteristics typical of continental orogenic volcanism as suggested by the absence of Fe enrichment evidences and the low $TiO_2$ content (Christofides; 1995). Products belongs to a calc-alkaline to high-K calc-alkaline and shoshonite series (Yanev et al., 1998).

Evros volcanic rocks includes intermediate to basic rocks and acid rocks exposed in three volcanic areas (fig): Loutros-Feres-Dadia; Kirki-Esimi; Mesti-Petrotà.

Loutros-Fere-Dadia is characterized by the occurrence of acid rocks, rapresented by rhyolite, in the northeastern and southwestern part, and by andesite and dacite in its central part.

The Kirki-Esimi area comprise dacite and rhyolite bodies but andesites are the most widespread in the area.

Even in the Mesti-Petrotà, andesites rapresents the prevailing products, followed by dacite and rhyolite.

## 4. Stratigraphy

Widespread extension in the Rhodope region from Late Eocene-Miocene times resulted in the development of a series of basins throughout the region. The basin infill provide a record of the nature of deformation in the area and allow the related tectono-magmatic-sedimentary evolution to be reconstructed.

Sedimentary successions of Southern Rhodopes are dislocated in two sub-basins: Xanthi-Komotini and Alexandroupolis.

The opening of these basin occurred during Lutetian in the Alexandroupolis area, while sedimentation in Xanthi-Komotini basin started at Priabonian. Both the basins show a general sedimentary trend evolving from continental to deep-marine environments. The development of these basins recorded the onset of a volcanic activity starting from lower Oligocene.

In Central-Eastern Rhodope the occurrence of sedimentation is documented since late Cretaceous. Intensive ductile and brittle deformation in the basement rocks are due to the formation and development of the Late Alpine extensional domes in the Central and the Eastern Rhodopes (Ivanov, 1998). In fact sedimentary fill and volcanics of the southwestern parts of the East Rhodope depression form the hanging wall of the detachment faults that bounds the exhumed high-grade cores of the Late Alpine domes. The basin subsidence and the formation of normal fault-bounded tilted blocks in the area southwest from Kardzali are linked with the activity of the Borovishka strike-slip zone. This zone is an array of dextral strike-slip faults, which are easy to trace in the area of Kobiliane-Kardzali. The lowermost sediments in this area build up a succession of coarse polygenic breccias of supposed Middle Eocene age. They are overlain by a succession of sandstones, limestones and tuffs. In the area of the village of Rusalsko, the mylonites of the Borovishka zone are sealed off by lower Oligocene intermediate lavas and lava-breccias. These relations constrain the age of the fault activity along the southwestern margin of East Rhodope depression between middle Eocene and early Oligocene.

Another important point is that in the Rhodopes Tertiary sedimentation have been synchronous to a tectonic activity. Evidence for that conclusion are ample: olistostromes, slumps and synsedimentary folds in the East Rhodope depression are noted by many of the previous investigators (Boyanov et al., 1963; etc). All these data clearly show that the formation of the Tertiary basin was controlled by the extensional faulting in the East Rhodopes.

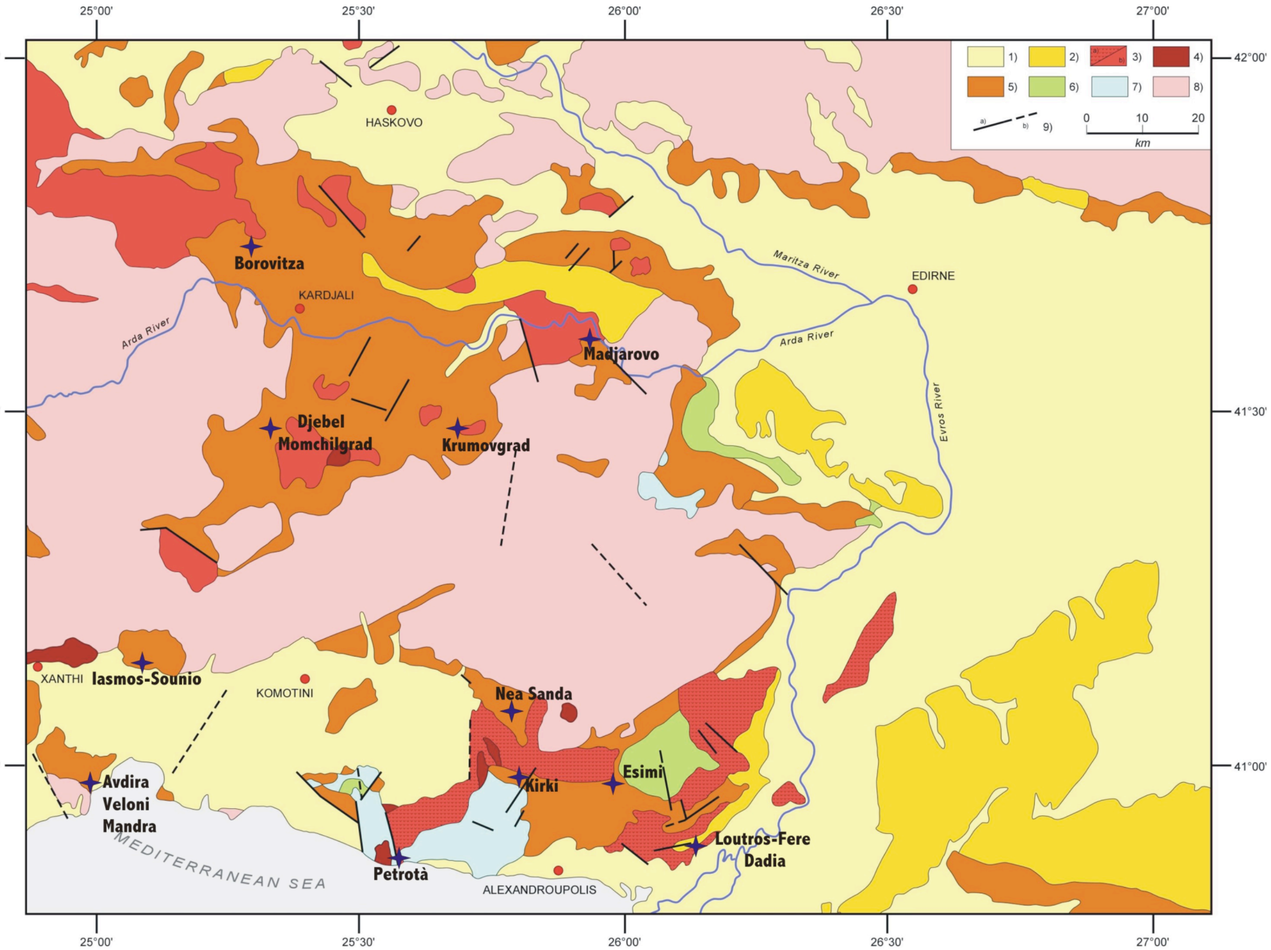
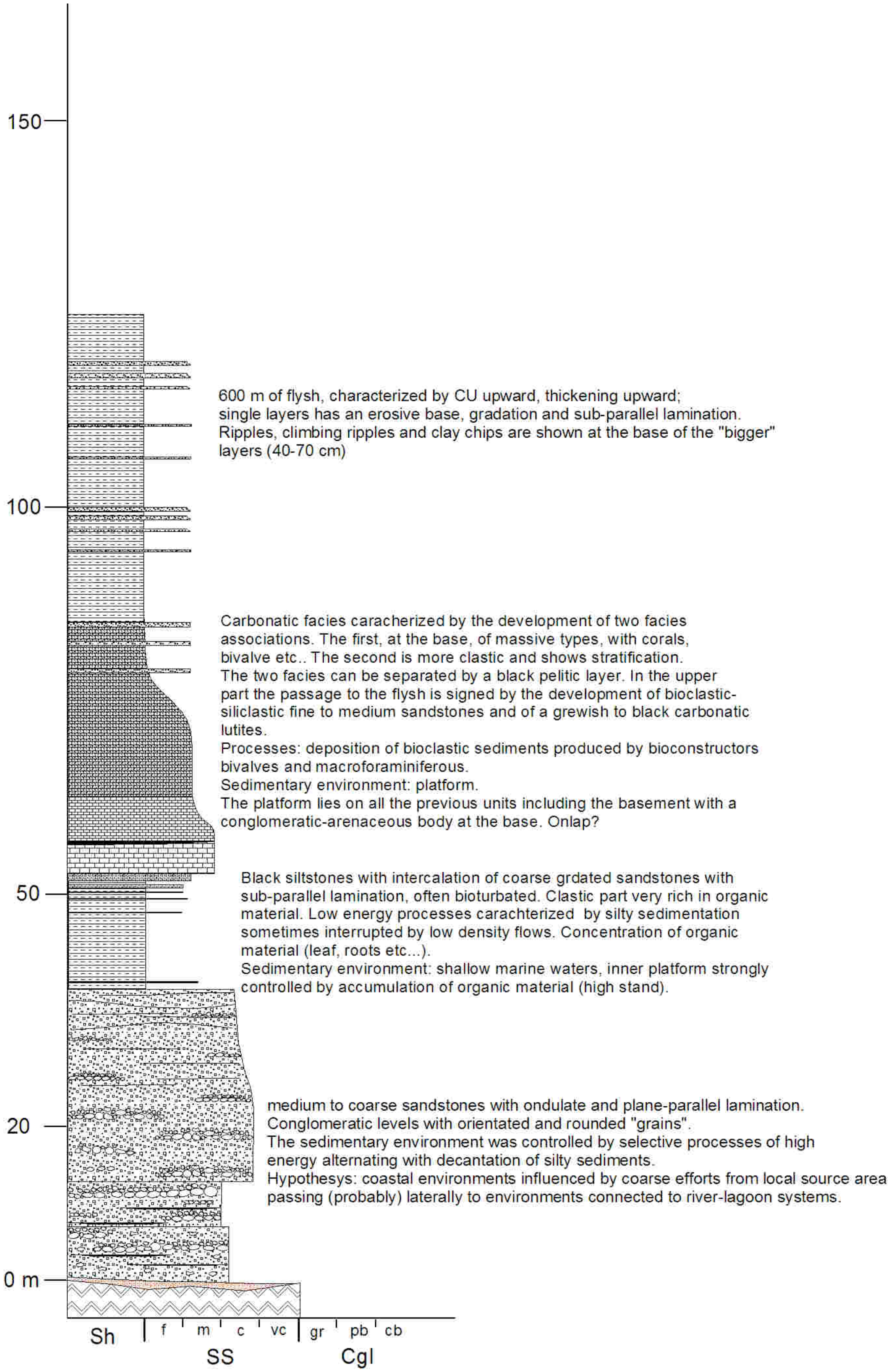
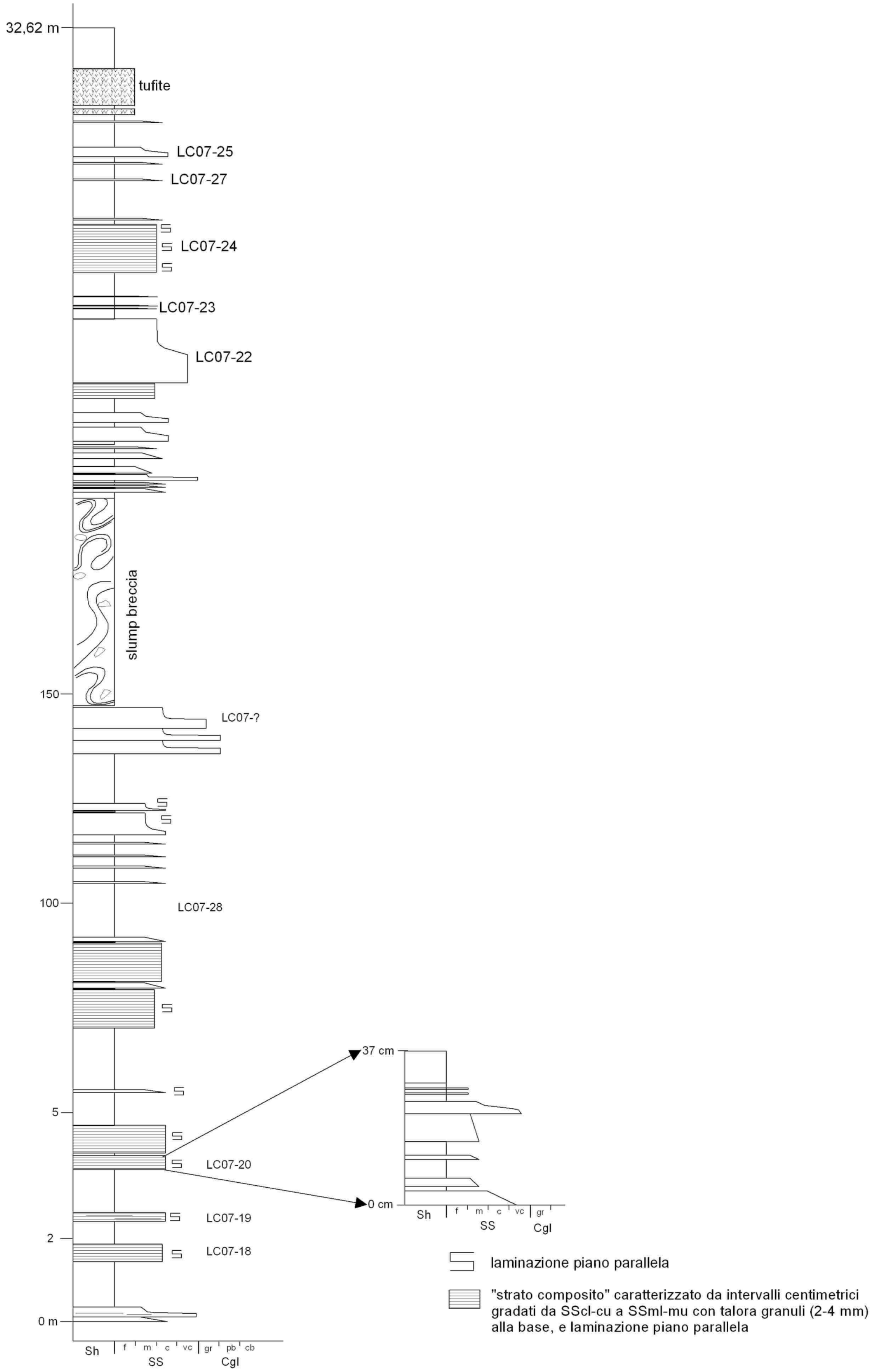


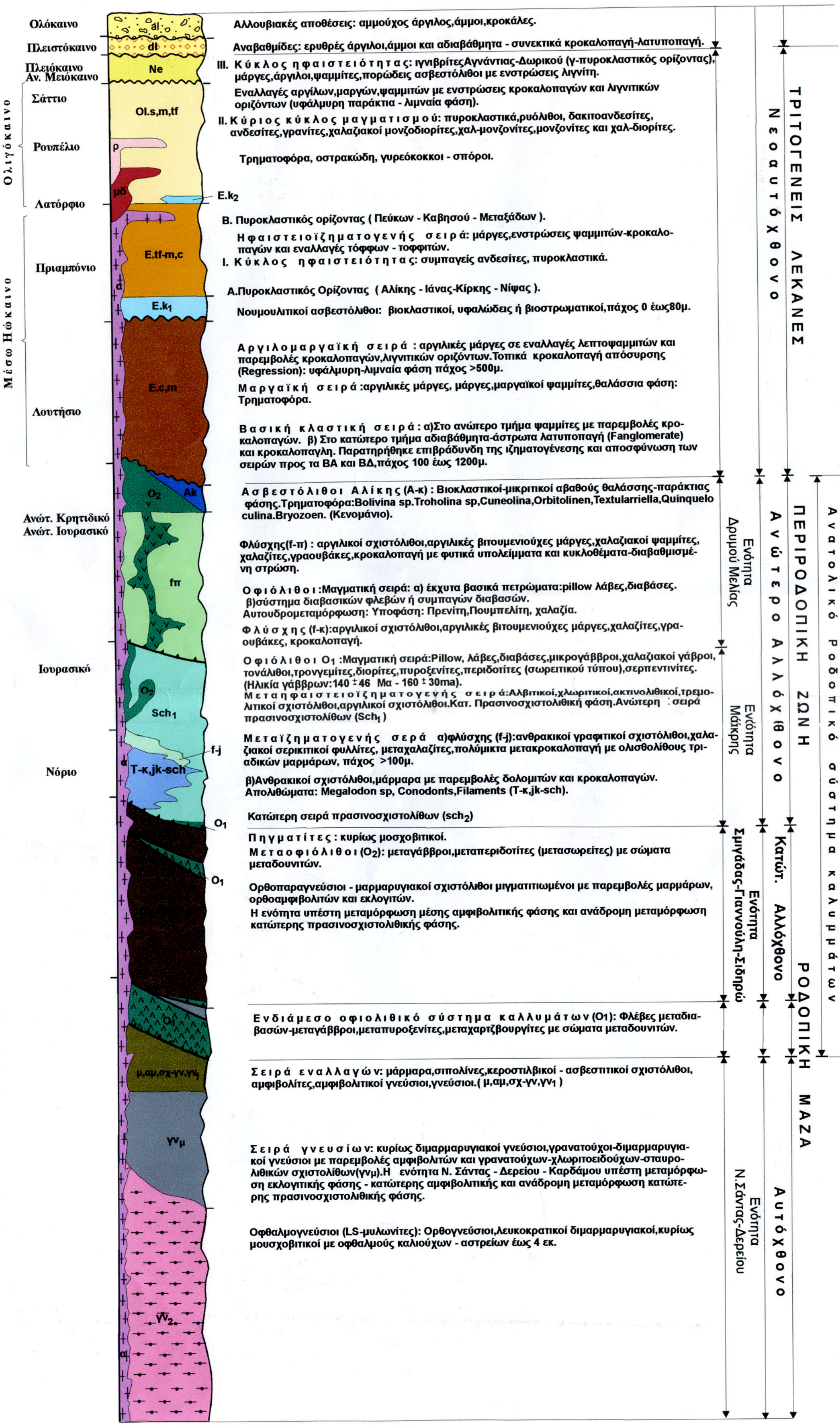

**Fig 5.1 Simplified geological map showing sampled areas. 1) Miocene-Quaternary marine and continental clastic deposits; 2) Oligocene marine and continental clastic deposits; 3) a: lower Oligocene and b: upper Eocene calc-alkaline lavas and pyroclastic rocks; 4) Oligocene intrusive rocks; 5)Upper Eocene continental clastic deposits, reef limestones and flysch successions; 6) Jurassic-Cretaceous epi-metamorphic and mafic-ultramafic magmatic rocks; 7) Triassic-Jurassic sedimentary and epi-metamorphic rocks (schists, marbles and intrusive rocks; 8)Metamorphic and magmatic rocks of Rhodope Massif; 9) a: faults; b: inferred faults**

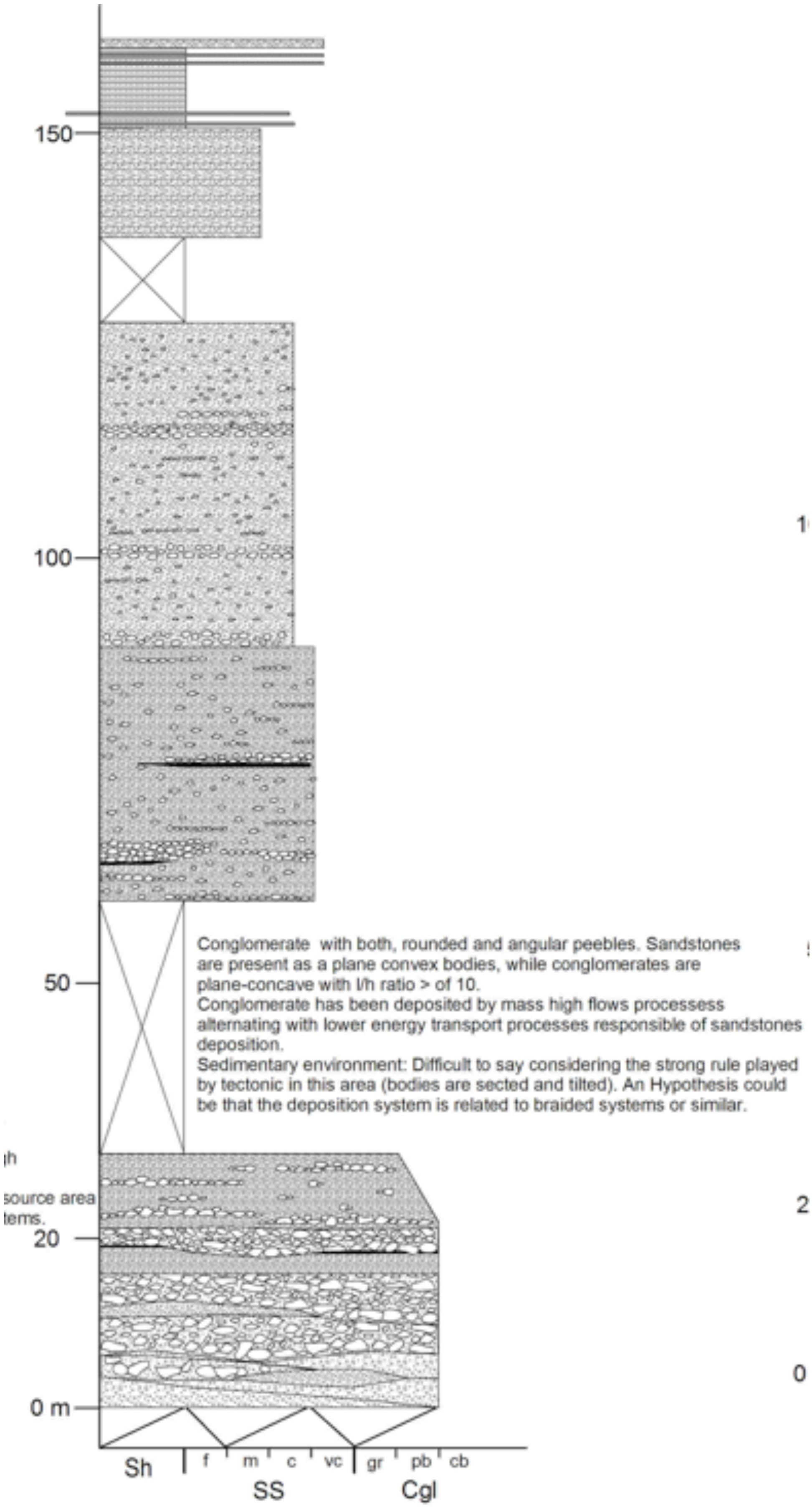

150
100
50
20
0 m
600 m of flysh, characterized by CU upward, thickening upward; single layers has an erosive base, gradation and sub-parallel lamination. Ripples, climbing ripples and clay chips are shown at the base of the "bigger" layers (40-70 cm)
Carbonatic facies caracherized by the development of two facies associations. The first, at the base, of massive types, with corals, bivalve etc.. The second is more clastic and shows stratification. The two facies can be separated by a black pelitic layer. In the upper part the passage to the flysh is signed by the development of bioclastic-siliclastic fine to medium sandstones and of a grewish to black carbonatic lutites.
Processes: deposition of bioclastic sediments produced by bioconstructors bivalves and macroforaminiferous.
Sedimentary environment: platform.
The platform lies on all the previous units including the basement with a conglomeratic-arenaceous body at the base. Onlap?
Black siltstones with intercalation of coarse grdated sandstones with sub-parallel lamination, often bioturbated. Clastic part very rich in organic material. Low energy processes carachterized by silty sedimentation sometimes interrupted by low density flows. Concentration of organic material (leaf, roots etc...).
Sedimentary environment: shallow marine waters, inner platform strongly controlled by accumulation of organic material (high stand).
medium to coarse sandstones with ondulate and plane-parallel lamination.
Conglomeratic levels with orientated and rounded "grains".
The sedimentary environment was controlled by selective processes of high energy alternating with decantation of silty sediments.
Hypothesys: coastal environments influenced by coarse efforts from local source area passing (probably) laterally to environments connected to river-lagoon systems.
Sh
f
m
c
vc
gr
pb
cb
SS
Cgl


32,62 m
tufite
LC07-25
LC07-27
LC07-24
LC07-23
LC07-22
slump breccia
150
LC07-?
100
LC07-28
5
LC07-20
LC07-19
2
LC07-18
0 m
Sh
f
m
c
vc
gr
pb
cb
SS
Cgl
37 cm
0 cm
laminazione piano parallela
"strato composito" caratterizzato da intervalli centimetrici gradati da SScl-cu a SSml-mu con talora granuli (2-4 mm) alla base, e laminazione piano parallela

## Σχ. 3 ΓΕΝΙΚΗ ΣΤΡΩΜΑΤΟΓΡΑΦΙΚΗ ΣΤΗΛΗ ΤΗΣ Ν.Α. - ΡΟΔΟΠΗΣ

Π. ΠΑΠΑΔΟΠΟΥΛΟΣ - Ι. ΑΝΑΣΤΑΣΙΑΔΗΣ




150
100
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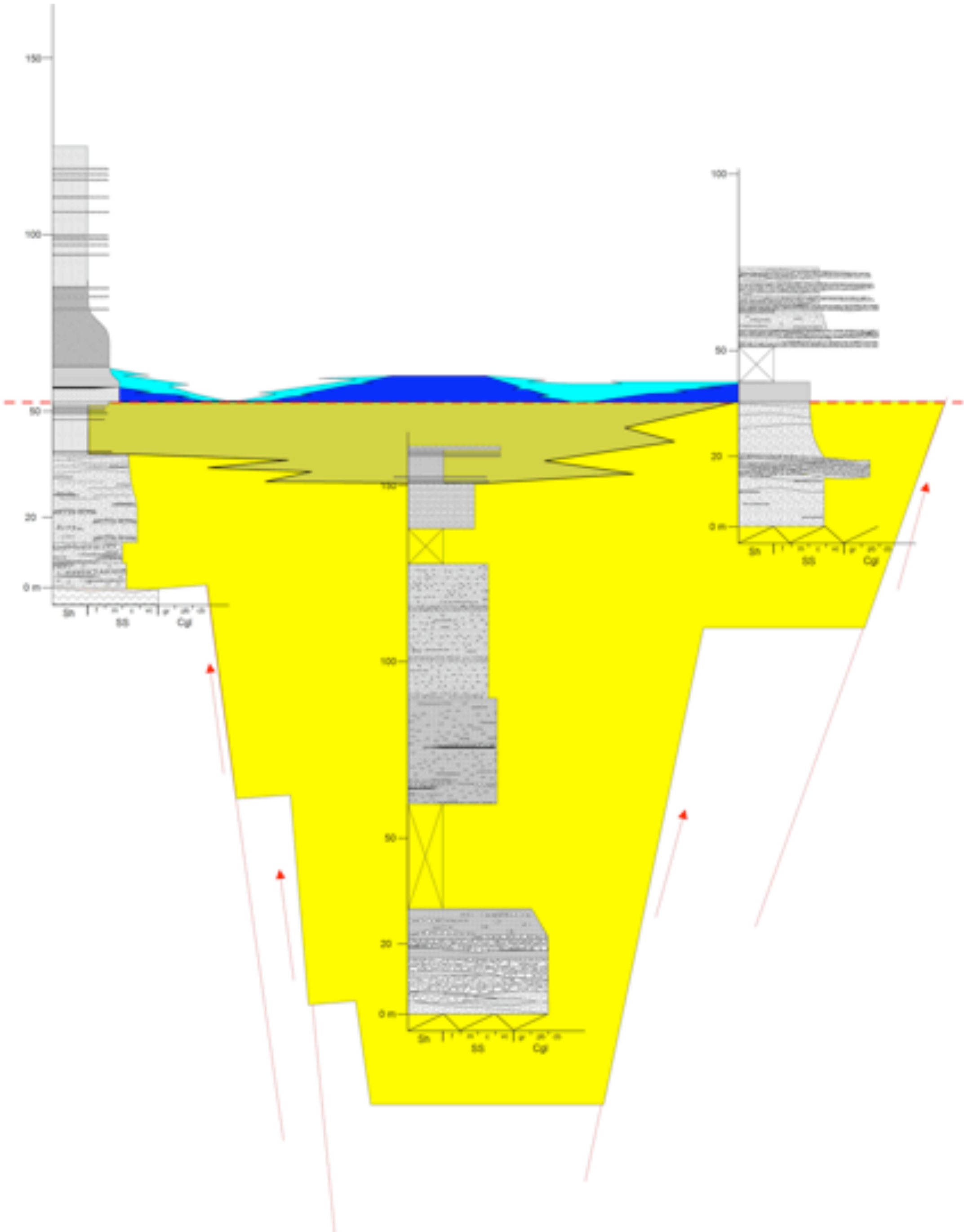
0 m
Conglomerate with both, rounded and angular peebles. Sandstones are present as a plane convex bodies, while conglomerates are plane-concave with l/h ratio > of 10.
Conglomerate has been deposited by mass high flows processess alternating with lower energy transport processes responsible of sandstones deposition.
Sedimentary environment: Difficult to say considering the strong rule played by tectonic in this area (bodies are sected and tilted). An Hypothesis could be that the deposition system is related to braided systems or similar.
source area
Sh
f
m
c
vc
gr
pb
cb
SS
Cgl



150
100
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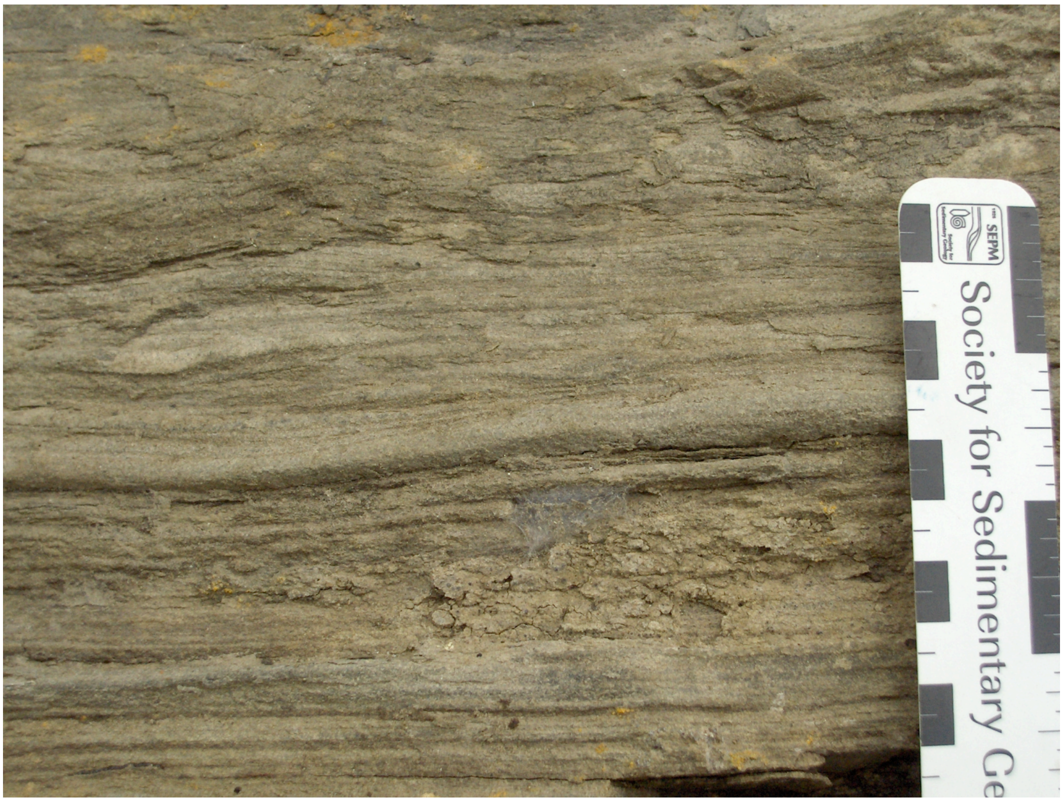
10
EURO
CENT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# 5.PETROLOGY AND PROVENANCE OF THE EOCENE-OLIGOCENE ARNITES

## 5.1 Sampling and methods

A total of 127 arenites samples have been collected widespread in Central and Southern Rhodopes. Concerning the latter we particularly concentrated our fieldwork in the sub-basin of Xanthi (see fig.) that includes the outcrops of Avdira, Sounio and Iasmos and in the sub-basin of Komotini – Alexandroupolis – Petrotà, especially in the areas of Kirki, Esimi, Nea Sanda, Leptokaria and Feres-Dada-Souflion volcanic area. Geographically all of these areas belong to the so-called "Greek Thrace".

Arenites amples from Central Rhodopes are part of the southeastern border of Bulgaria with Greece and Turkey. The main sampled areas are: Borovitza-Arda, Krumovgrad, Djebel, Madjari, Chernochene, and Perunika.

All the arenites used for the petrographic analysis are medium or medium to coarse in grain-size.

The thin sections derived from sampling have been treated with hydrofluoric acid and the sodium-cobalt-nitrite in order to recognize plagioclase grains and the staining of the alkaline feldspar respectively.

Procedures and methods for the petrographic analysis of samples, principally consists of arenites modal analysis using the point counting tecnique at the optic microscope. A minimum of 425 points has been counted in order to analyse the framework and interstitial components. The tecnique used for the point counting is the one introduced by Gazzi (1966) and modified by Dickinson (1970). This tecnique has the advantage to reduce the effect of the grainsize on composition, expressed by the increasing of the polimineralic grains with coarse textures with the increasing of the sample's grainsize (Ingersoll *et al.* 1984; Zuffa, 1985).

The framework composition has been recalculated using the compositional parameters introduced by Ingersoll and Suczeck (1979), Zuffa (1985) and Critelli and Ingersoll (1995). Recalculations are shown in appendix 1

## 5.2 Framework composition

**NCE (non-carbonate extrabasinal grains)**

*Quartz*

*Quartz (single crystal)*

Quartz grains is the dominant detrital population and is characterized by a variable grainsize and different roundness index (between angular and sub-rounded).

Some grains shows dense mineral inclusions, such as of rutile, suggesting a provenance from metamorphic source rocks. This grain type generally occurs with a maximal concentration of 35 % and is often absent in volcaniclastic samples

*Policrystalline quartz with tectonic fabric*

This type of grains are generally composed by three or more single quartz grains suggesting a provenance from phyllite – schists source rocks (Basu et al., 1975) (plate 1.c) and occurs with a maximum concentration of 26 % of the total framework grains

*Policristallyne quartz without tectonic fabric*

This type of grain occurs rarely compared to the other and shows a maximum concentration of 10%.

*Quartz in metamorphic rock fragment*

This petrographic class is dominantly represented by quartz grains within low grade metamorphic rocks such as phyillite to schists and medium - high grade metamorphic rocks like fine grained schists and gneiss. These grains are normally associated with other quartz grains with stilolithic contacts and/or with feldspars and micas. The occurrence of this grains reaches, a maximum of 34 %.

*Quartz in plutonic rock fragment*

Concentration of plutonic rock fragment is generally low as shown by a maximum occurrence of 8 %. These types of grains usually are found with a mineral association of quartz, k-feldspar, plagioclase and micas and a higher sphericity value compared to the others, from sub-rounded to rounded.

*Quartz in plutonic or gneissic*

This class is usually used for grains of uncertain provenance between igneous and high-grade metamorphic source rocks. Concentration of these grains does not reach a value of 5 %.

*Feldspars*

*K-Feldspars (single crystals)*

It generally occurs as microcline and orthoclase, sometimes showing clear evidences of pertithic mixing with a mean concentration of 15%. In some of the volcaniclastic arenites the sanidine grain type has been recognized. Alteration of k-feldspars is mostly attributable to neo-formation of clay minerals and, subordinately, to sericitization.

*K-Feldspars in metamorphic rock fragment*

The mean concentration of the potassic feldspar in metamorphic rock fragment is 4 % and is generally associated with quartz and phyllosilicates.

*K-Feldspars in plutonic rock fragment*

The occurrence of K-feldspars in plutonic rock fragments is higher if compared to metamorphic rock fragments. Concentration of these petrographic classes has a maximum value of 12 % of the total framework.

*Calcite substition on K-Feldspars*

Is strongly related to the presence of the carbonate cements and has a maximum concentration of 2 %.

*Plagioclase*

*Plagioclase (single crystal)*

Very often plagioclases show an albite type twinning and zonations. These grains are characterized by a very low sphericity index and typically show different processes of alteration, but mostly to sericite. They represents the most common crystal in volcaniclastic samples where often appears as the only feldspar type with a typical euhedral shape. The mean concentration reaches a 23 % value.

*Plagioclase in metamorphic rock fragment*

Plagioclases are quite often associated with quartz and phyllosilicates as muscovite and biotite attributable to low to medium metamorphic rocks, such as phyllite and schists, and higher metamorphic grade rocks as fine grained gneiss, or green schist facies rocks in association with epidote. Concentration of this petrographic class is 5 %.

*Plagioclase in plutonic rock fragments*

Is the less represented petrographic class among feldspar showing a maximum concentration of 2 %

*Plagioclase in volcanic rock fragment*

It is frequent in volcaniclastic arenites, especially in the basaltic to andesite derived where sometimes is possible to recognize the albite twinning and its original shape. Is often substituted by epidote probably due to hydrothermal processes and by calcite. It occurs with a maximum concentration of 17%.

*Calcite replacement on Plagioclase*

The replacement of calcite is very often associated with carbonate-cemented arenites. In this samples the concentration of replacements reaches the 5 %.

*Micas*

In the analyzed samples micas are very well represented. Micas usually occurs as single crystal, mostly as chlorite and biotite, in phaneritic metamorphic (rarely represented by chlorite schists) and plutonic rocks.

*Heavy minerals*

A wide range of heavy minerals has been recognized. Epidotes are the most abundant showing a strong concentration in the volcaniclastic arenites where it reaches the 4 %. Amphiboles of different types are present in the analyzed samples, mostly rapresented by green hornblende, actinolite and clinozoisite. Other recognized dense minerals are garnet, piroxenes, zircon, rutile and sphene.

**Lithics**

In this petrographic class are included only the aphanitic lithic grains in order to avoid the composition dependance from the grain size (Ingersoll et al., 1984). Different types of lithic fragment have been recognized. These grains are rapresentative of a dominantly different grade metamorphic and volcanics source rocks and subordinately of plutonic, ophiolitic and sedimentary (carbonate related) source rocks.

*Metamorphic lithic grains*

The metamorphic lithic grains commonly shows different grade of foliation, recrystalization and schistosity. For classification the criteria proposed from Garzanti & Vezzoli (2003) has been followed. The most common grains are phyllite (occurring with a maximum concentration of 48%) mostly composed by quartz and micas, schists (0-23 %) of various type (muscovite schist, chlorite schist, epidote schist and serpentine schists) including mostly association of quartz, micas and feldspars and rarely with heavy minerals such as garnet, epidote, and different amphiboles like actinolite and clinozoisite.

*Volcanic lithic grains*

This petrographic class is almost exclusive of volcaniclastic arenites. Here the criteria introduced by Critelli and Ingersoll (1995) for temporal discrimination has been adopted. The grains derivated from the erosion of ancient volcanic complexes are defined as paleo-volcanic while the grains generated by an active volcanism, syncronous to deposition are defined as neo-volcanic.

The analyzed volcaniclastic samples are extremely rich in neo-volcanic lithic fragment, showing different textures according with different magmas compositions. The non-volcaniclastic sandstones are pratically free of volcanic lithic grains with the exception of three samples including few paleo-volcanic grains. According with Dickinson (1970), Marsaglia and Ingersoll (1992), Critelli & Ingersoll (1995) and Critelli et al. (2002) four different volcanic textures have been recognized.

*Lathwork texture:* the lithic fragments showing this texture presents phenocrysts of the sand grain size in a glass groundmass or microcristalline glass. Phenocrysts are mostly represented by plagioclase and rarely by olivine and pyroxenes. The occurrence of this type of lithic fragments is minor in our sandstones with a maximum concentration of 4%. The groundmass commonly is brown to orange in colour.

*Microlitic texture:* is typical of lithic fragments with microlithes of plagioclase and iron and magnesium high minerals according with an andesitic or basaltic – andesitic volcanism. Is the most represented grain in our volcaniclastic sandstones with a maximum concentration of 48 %.

*Vitric texture:* is typical of volcanic lithic fragments represented by pumice and shards. It includes glasses showing different type of alterations such as silicitization, devetrification and zeolitizations as described by Dickinson (1970) Ingersoll & Cavazza (1991) and Marsaglia (1992). In some of the analyzed samples this texture reaches the 60 % including a very high content in pumice and shards.

*Felsitic texture:* this texture is usually characterized by a siliceous groundmass with phenocrysts of quartz, plagioclase and sandine and rarely biotite and horneblende. It consists of two types, the felsitic granular and the felsitic seriate, both typical of intermediate to felsic volcanism, from andesite and dacite to rhyolite (Ingersoll & Cavazza, 1991; Critelli et al., 2002). The occurrence of this texture is limited to 4 samples where it reaches the 3 % in concentration.

*Sedimentary lithic grains (Ls)*

The occurrence of sedimentary lithic grains is extremely low in the analyzed arenites. The most important contribute is given by extrabasinal carbonates, including micritic limestones, sparitic limestones, biosparitic, biomicritic and foliated limestones (CE, Zuffa, 1980). Other sedimentary lithic fragments recognized are few grains of silststones and cherts.

*Carbonate and non-carbonate intrabasinal lithic grains (CI and NCI, Zuffa, 1980).*

This petrographic class is dominantly represented by bioclast fragments, principally Alveolinae and Nummulites, and subordinately by iron oxides and rip-up clasts.

### ***Matrix and cements***

*Matrix*

Detrital matrix is represented by siliclastic matrix, usually silty, quartzose and micaceous in composition. Concentration reaches the 25 %. In volcanic sandstones a volcaniclastic matrix has been recognized with a maximum concentration of 16 %.

*Cements*

*Carbonate cements*

Different types of cement characterize the analyzed arenitic detritus. The highest content has been obeserved for carbonate cements that largely occurs in all Central Rhodopes arenites groups (quartzolithic, volcaniclastic and quartzosefeldspathic), while in Southern Rhodopes it preferentially concentrates in quartzosefeldspathic sandstones and rarely in volcaniclastic and quartzolithic. Cements are represented by spatic calcite as patchy calcite (0 – 30 %) or as pore filling (0-23%).

*Phyllosilicate cements (Kaolinite, Illite)*

Phyllosilicate cements are characteristic and highes in concentration for quartzolithic sandstones of Southern Rhodopes (0 – 27 %). These cements could be related to a replacement of altered detrital. As concequence it results in a predominance of kaolinite (between phyllosilicate cements) sometimes alternating with illite.

*Siliceous cements*

Siliceous cements occur rarely (0-16 %) in the analyzed sandstones. It has been recognized only in Southern Rhodope sandstones often in association with the kaolinite cements mentioned above. Quartz overgrowth (0-1%) has been observed on detrital quartzose grains. The boundary between grains and overgrowths is commonly characterized by a dust line (Pittman, 1972).

*Other cements*

Very rarely other type of cements has been observed such as grain coats from clay minerals (0-1,5 %) and iron oxides cements (0-3%).

## 5.3 PETROFACIES

The concept of sedimentologic petrofacies, in terms of sediment composition rather than lithology, has been introduced in the early 1970s by Dickinson (1970), Gilbert and Dickinson (1970), Dickinson and Rich (1972).

Consideration of clastic sedimentary packages based on thei compositional similarity rather than on gross lithologic character has proven useful both in the evaluation of source regions and their evolution over time, and in regional correlation (Stanley, 1976; Ingersoll, 1978, 1983, 1990; Dickinson et al., 1982, 1983b; Ingersoll et al., 1990; Ingersoll and Dickinson, 1990; Ingersoll and Cavazza, 1991). Petrofacies may reflect not only similarities in source rock, but in any of the factors influencing sediment composition (Suttner, 1974; Suttner and Dutta, 1986; Jonsson et al., 1991).

On the base of Rhodopes sandstones detrital modes three petrofacies have been defined: a) Quartzolithic petrofacies; b) Quartzose-feldspathic petrofacies; c) Volcaniclastic petrofacies. Those petrofacies are characteristic and rapresentative of the evoultion of the accretionary processes and the development of a volcanic activity in the northeastern mediterranean between the Middle Eocene (Lutetian) and the Oligocene.

### 5.3.1 Quartzolithic petrofacies

The quartzolithic petrofacies (plate 1) clearly shows evidences of metamorphic source rock supply with $Qt_{67}F_{15}$ $L_{18}$ (plate 1.a) and $Qm_{60}$ $F_{15}$ $Lt_{17}$ (plate.1.b). Between feldspars, plagioclase is the most rapresented as shown by $Qm_{75}$ $K_{11}$ $P_{14}$ (plate 1.c). Quartzolithic sandstones are extremely rich in quartz, both, as single crystal and polycrystalline, particularly with tectonic fabric ($Qp_{37}$ $Lvm_{0}$ $Lsm_{63}$) (plate.1.d). Plagioclases and K-feldspars usually occur as single crystals and occasionally in metamorphic and plutonic rock fragments. Aphanitic lithic grains consists mostly of low-grade metamorphic rock fragments ($Lm_{97}$ Lv0 $Ls_{3}$) (plate.1.e) and secondly of medium to high-grade metamorphic rock fragments such as amphibolite and serprentinite. Phaneritic lithic grains ($Rg_{23}$ $Rv_{0}$ $Rm_{77}$) (plate.1.f) occurs in minor percentage compared to the aphanitics and mainly consists of medium to high-grade metamorphic rocks, mostly gneisses, and rarely of plutonic rock fragments rapresented by association of quartz, plagioclase and K-feldspar. Sedimentary lithic grains are rare and predominantly consist of extrabasinal carbonates such as micritic, biomicritic and foliated limestones. Carbonatic detritus is limited and rapresented by bioclasts.

The ancient sandstones of this petrofacies are Lutetian in age and rapresents the beginning of sedimentation in the whole area. These are concentraded in the Kirki-Esimi area (fig.5.1) and are extremely rich in low-grade metamorphic rock fragments as phyllite (plate.2.c-d). Quartzolithic from Borovitza-Arda, in Central Rhodopes, are similar to Lutetian sandstones in framework composition, but are characterized by the appreciable content in serpentinite fragments (plate.2.e) confirming the Low-grade Mesozoic Unit and the Variegated Complex as the predominant source area from Lutetian to Priabonian. Oligocene quartzolithic sandstones of southern Rhodopes (Mandra and Avdira sections) are richer in plutonic rock fragments and are characteristics for cements. Samples from the lower part of succession (samples from SC 746 to SC 752) shows high contents of carbonate cements decreasing and disappearing moving upward in the sedimentary succession. The lower part is separated from the upper part by a carbonatic platform, where corals are the dominant species. The upper part (samples from SC 753 to SC 758) is extremely low in feldspars that clearly show evidences of dissolution and replacement by kaolinite (plate.2.a). Cements are dominantly rapresented by phyllosilicates, particularly by kaolinite, sometimes alternating with illite (plate 2.b) and quartzose cements.

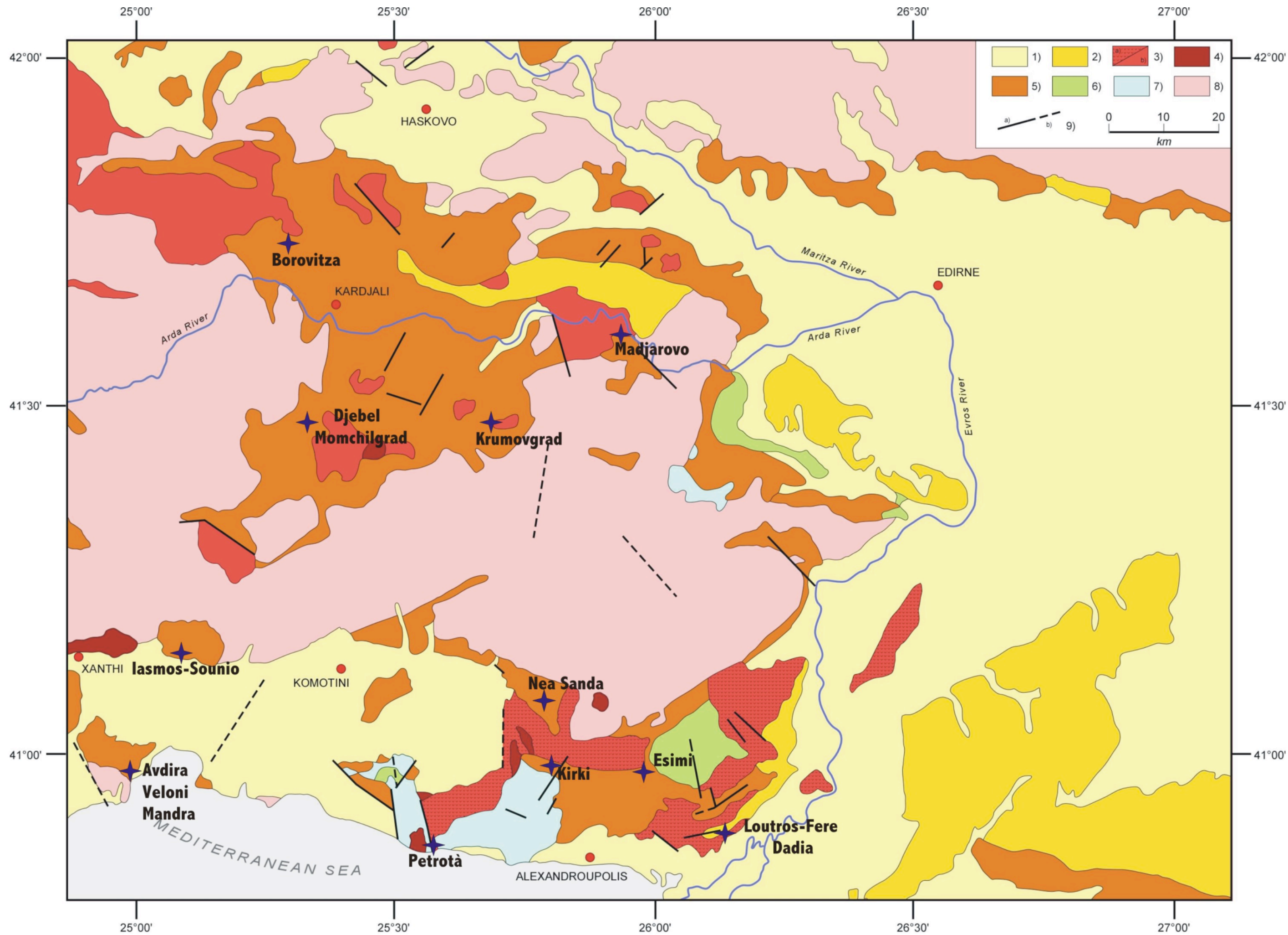



**Fig 5.1 Simplified geological map showing sampled areas. 1) Miocene-Quaternary marine and continental clastic deposits; 2) Oligocene marine and continental clastic deposits; 3) a: lower Oligocene and b: upper Eocene calc-alkaline lavas and pyroclastic rocks; 4) Oligocene intrusive rocks; 5)Upper Eocene continental clastic deposits, reef limestones and flysch successions; 6) Jurassic-Cretaceous epi-metamorphic and mafic-ultramafic magmatic rocks; 7) Triassic-Jurassic sedimentary and epi-metamorphic rocks (schists, marbles and intrusive rocks; 8)Metamorphic and magmatic rocks of Rhodope Massif; 9) a: faults; b: inferred faults**

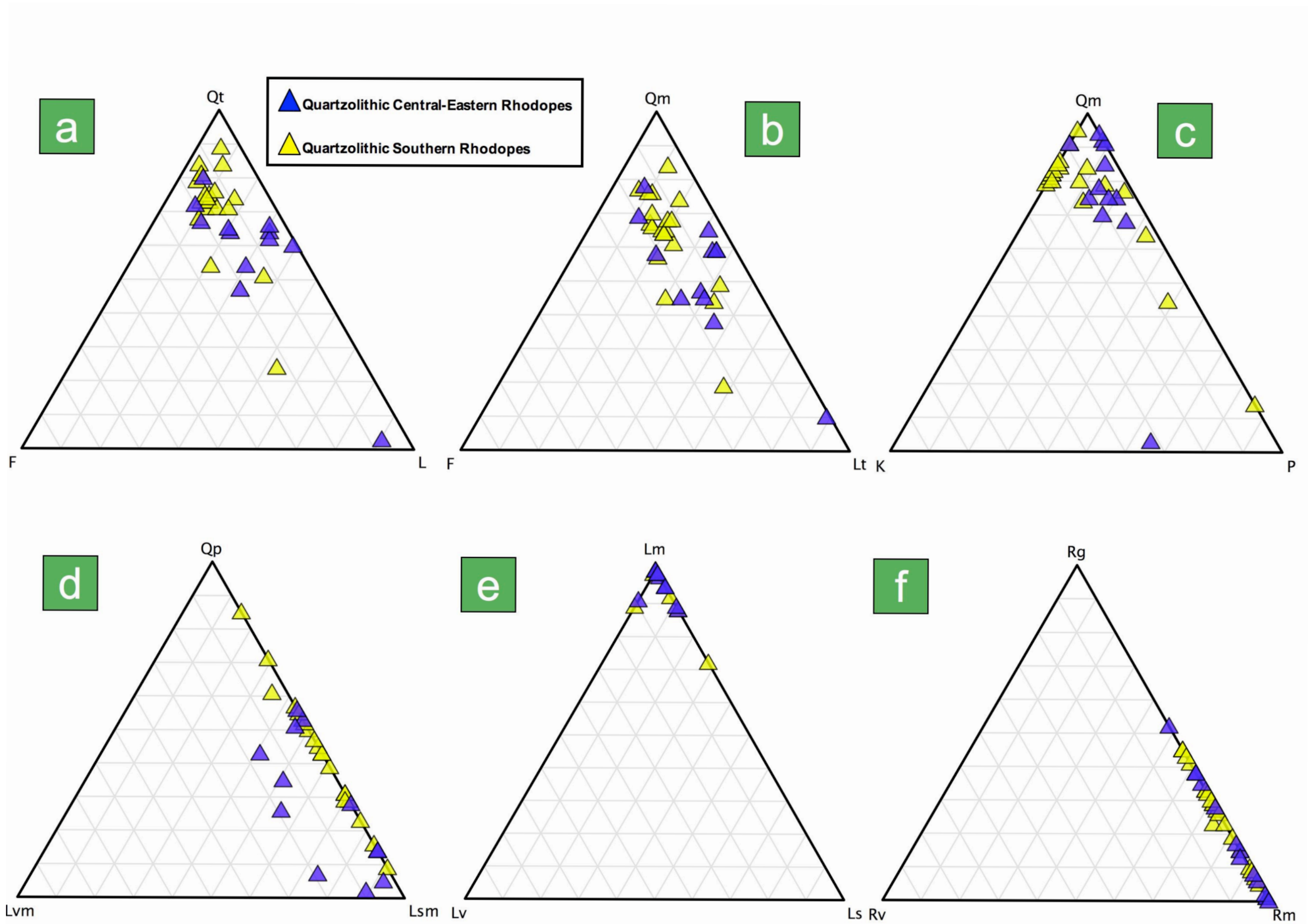
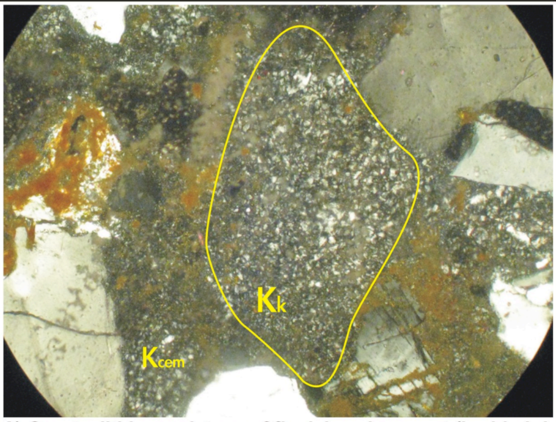
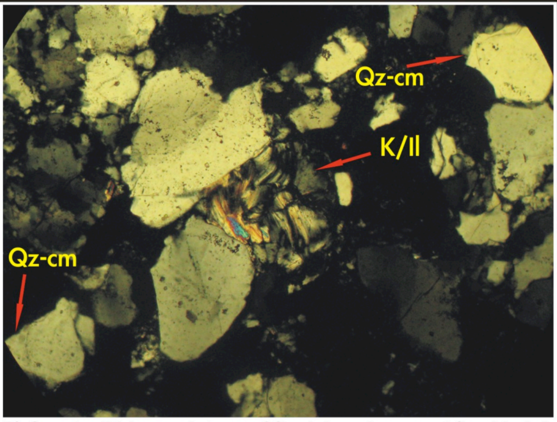


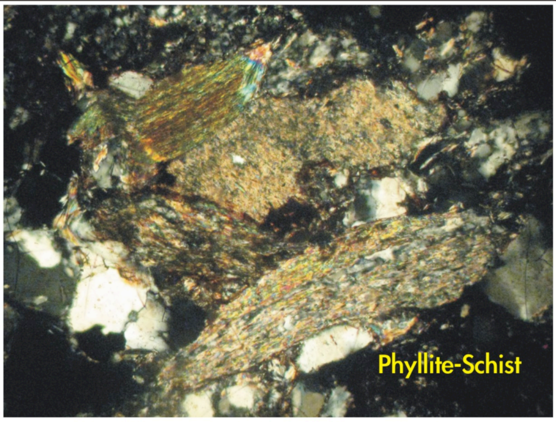

Plate 1. Ternary plots of detrital modes of quartzolithic petrofacies of Rhodopes sandstones. A) Qt (total quartz); F (Feldspars); L (fine grained lithics – Qp); Qm (monocrystalline quartz); Lt (fine grained lithics + Qp); K (K-feldspars); P (Plagioclases); Qp (policrystalline quartz); Lvm (meta-volcanic lithic grains); Lsm (metasedimentary lithics); Lm (metamorphic lithics), Lv (volcanic lithics); Ls (sedimentary lithics), Rg (granitoid rocks); Rv (volcanic rocks); Rm (metamotphic rocks).



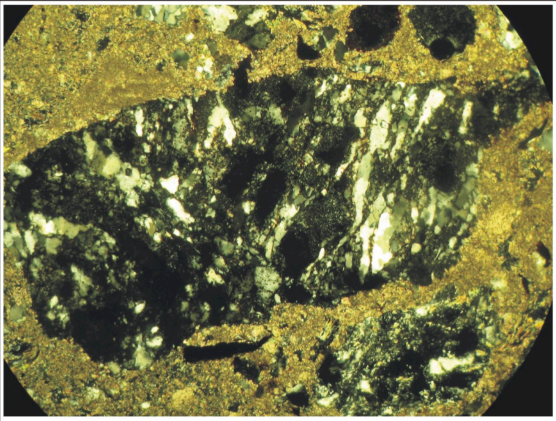

*A) Quartzolithic sandstone of fluvial environment (braided river) of Southern Rhodopes (Avdira).Kk :Relict of k-feldspar grain substituted by kaolinite. Kcem:kaolinite cement.(10x)*



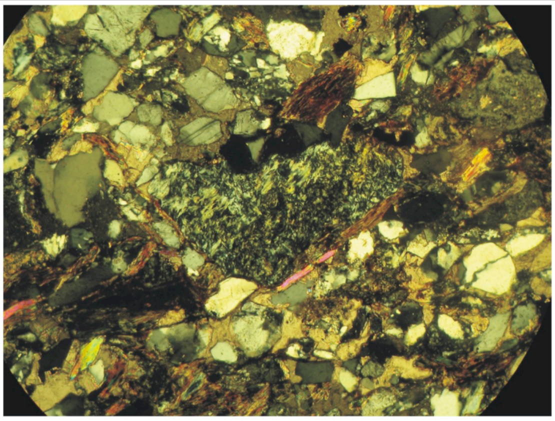

*B) Quartzolithic sandstone of fluvial environment (braided river) of Southern Rhodopes (Avdira). K/Il: alternation Kaolinite Illite. Qz-cem: quartz overgrowth.(10x)*



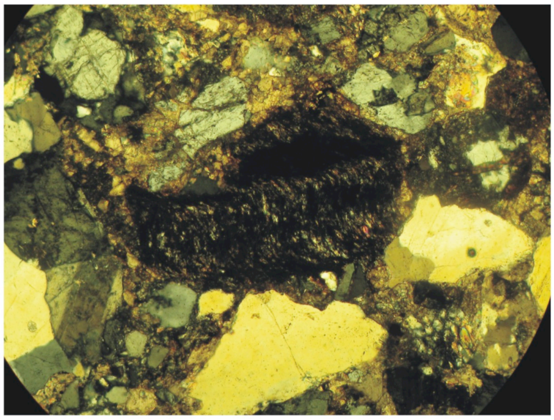

*C) Phyllites and schists lithic fragments in quartzolithic sandstone. Southern Rhodopes (Esimi).(10x)*



*D) Policrystalline quartz with tectonic fabric surrounded by carbonate cement. Central-Eastern Rhodopes.(10x)*



*E) Quartzolithic sandstone with ophiolite-related lithic fragment of serpentinite schist. Central-Eastern Rhodopes. (10x)*



*E) Metasedimentary lithic grains (slate) in quartzolithic sandstone with carbonate cement. Central-Eastern Rhodopes. (10x)*

Plate 2. Opitcal microscope microphoto of quartzolithic petrofacies sandstones. A) Kaolinite cement and substituion on K-feldspar; B) Kaolinte /Illite alternation and quartz overgrowth cements. C-D-E-F: Metamorphic lithic grains of Central-Eastern and Southern Rhodopes sandstones. Respectively: Phillyte and schist, policrystalline quartz with tectonic fabric, serpentinite schist and slate. Magnification 10x. Crossed Nichols.

### 5.3.2 Quartzosefeldspathic petrofacies

Quartzosefeldspathic petrofacies is chracterized by equivalent percentage of quartz and feldspars as shown by detrital modes recalculations: $Qt_{48}$ $F_{46}$ $L_6$ (plate 3.a); $Qm_{46}$ $F_{46}$ $Lt_6$ (plate 3.b). Quartz occurs as single crystal and polycrystalline quartz with tectonic fabric ($Qp_{31}$ $Lvm_6$ $Lsm_{63}$) (plate 3.d) and dominantly in high-grade metamorphic rocks as gneiss and rarely in granitoids rock fragments as evidenced by the association of quartz, k-feldspars and (less) plagioclases. Feldspars generally occurs both as single crystal and in rock fragments of metamorphic and plutonic affinity. Plagioclases are dominantly compared to k-feldspars ($Qm_{50}$ $K_{18}$ $P_{32}$) (plate 3.c).

Phaneritic rock fragments ($Rg_{26}$ $Rv_0$ $Rm_{74}$) are rapresented by low to medium grade metamorphic rocks showing associations of quartz, k-feldspars and phyllosilicates, and green-schist facies rocks extremely high in epidote, and high-grade metamorphic rock fragment such as gneiss. Plutonic lithic fragments occur in minor concentrations.

Aphanitic lithic grains ($Lm_{76}$ $Lv_6$ $Ls_{18}$) (plate 3.e) mainly consists of metamorphic fragments rapresented by phyllite, chlorite-schists and muscovite-schists and rarely by paleovolcanic lithic fragments with microlitic texture.

Quartzosefeldspatic sandstones from Southern Rhodopes shows significantly differences from equivalent in composition Central Rhodopes sandstones. Southern Rhodopes samples has appreciable content of lithic fragment of different origin, but are characteristic the ones from Esimi-Leptokaria area for extremely rich epidote metamorphic rock fragments. This grains commonly presents association of epidote and amphibole, mostly hornblende transformed in actinolite, suggesting a high-grade protolith retrograded in greenschist facies provenance (plate 4.b). Central Rhodopes sandstones clearly show low contents in lithic fragments generally limited to extrabasinal carbonates.

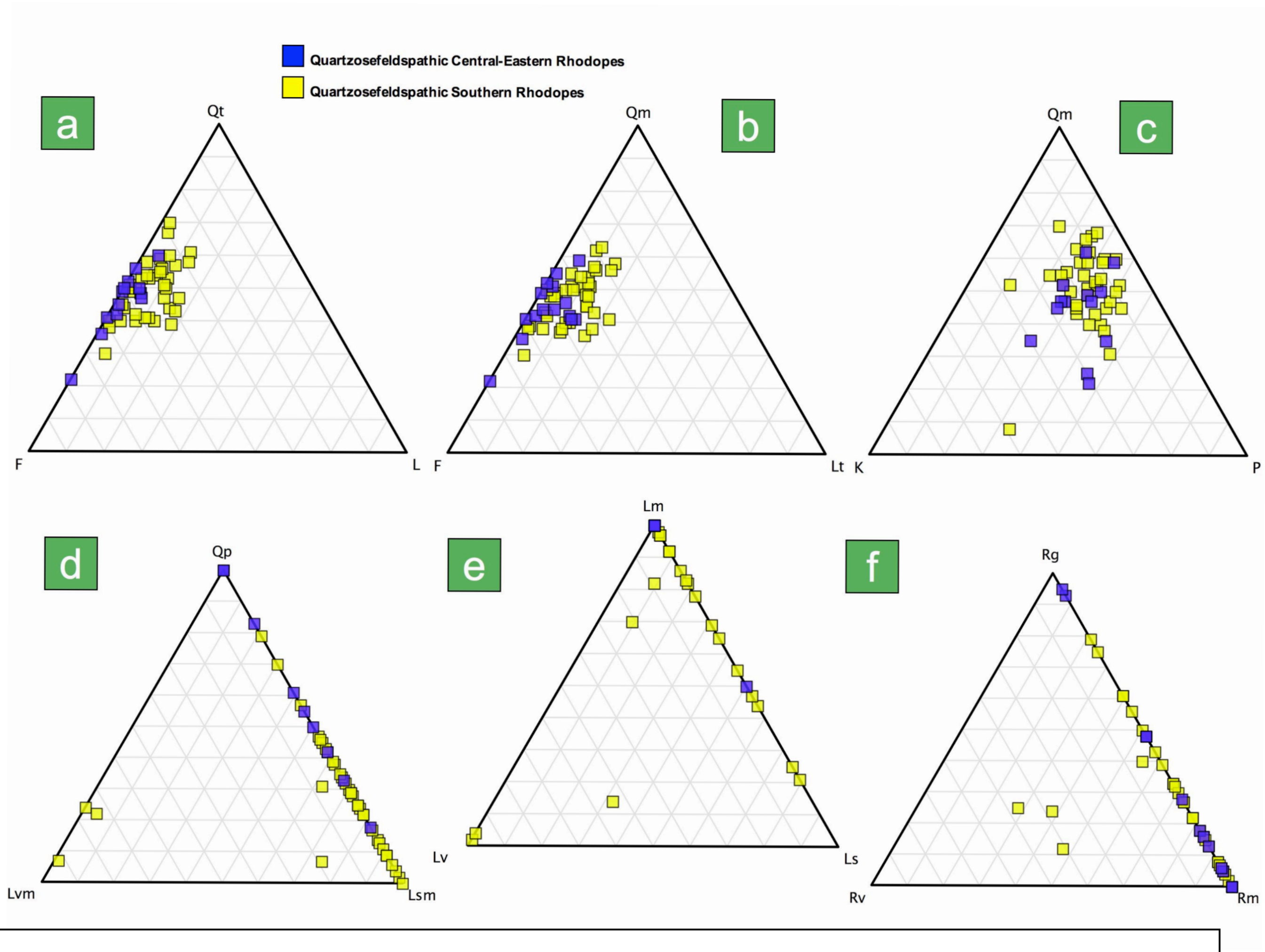
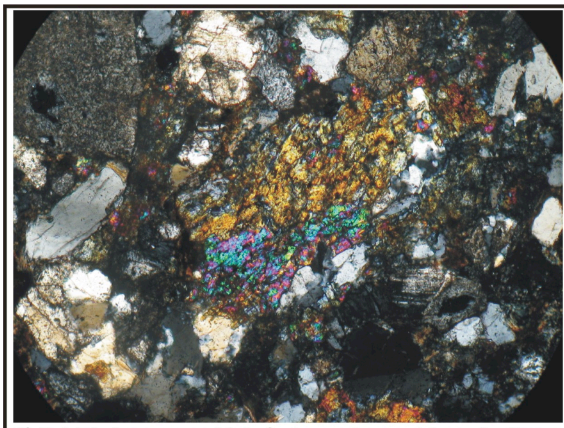
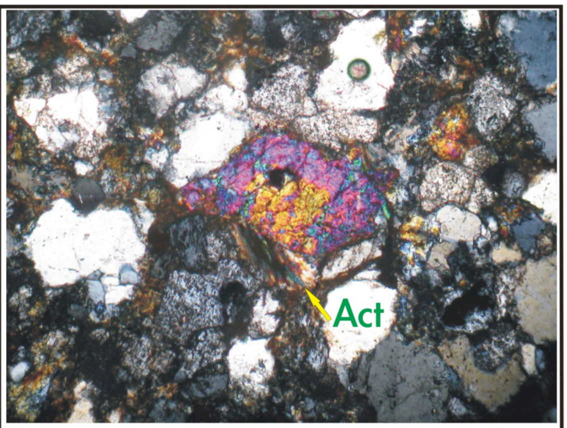


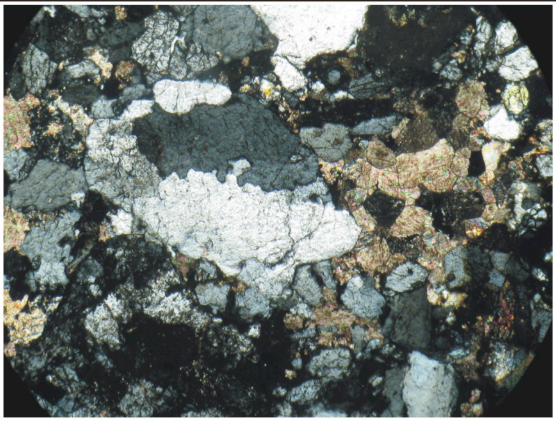

Plate 3. Ternary plots of detrital modes of quartzosefeldspathic petrofacies of Rhodopes sandstones. A) Qt (total quartz); F (Feldspars); L (fine grained lithics – Qp); Qm (monocrystalline quartz); Lt (fine grained lithics + Qp); K (K-feldspars); P (Plagioclases); Qp (policrystalline quartz); Lvm (meta-volcanic lithic grains); Lsm (metasedimentary lithics); Lm (metamorphic lithics), Lv (volcanic lithics); Ls (sedimentary lithics), Rg (granitoid rocks); Rv (volcanic rocks); Rm (metamotphic rocks).



*A) Epidote in green-schists facies metamorphic grain. Deep-marine succession of Southern Rhodopes (Esimi). (10x)*

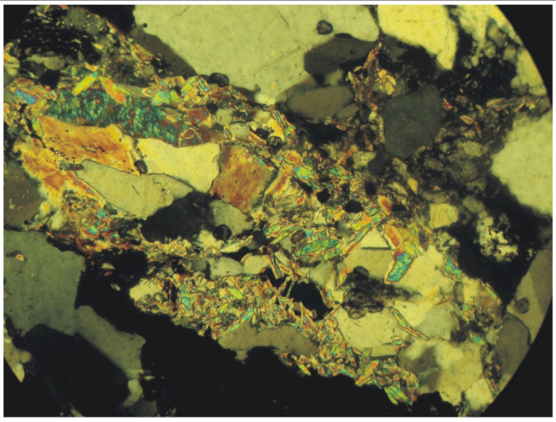



*B) Epidote in green-schist facies metamorphic grain. Here associated is actinolite, retrograded from hornblende, testifying retrogradation from higher grade protolith. (10x)*

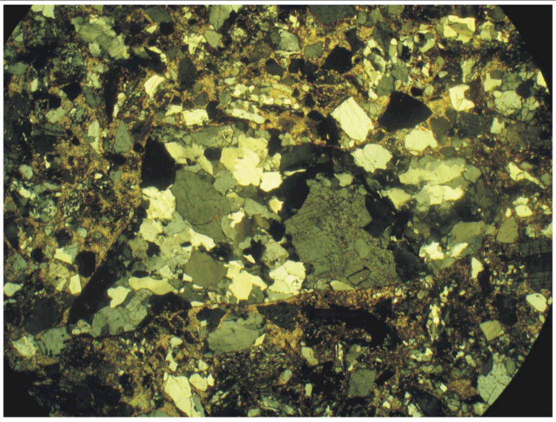


*C) Gneissic lithic fragment composed by quartz, plagioclase, and small k-feldspars cemented by patchy calcite type carbonate cement. Southern Rhodopes (10x)*

*D) Silty to arenitic limestone. Typical of deep marine sandstones of Central-Eastern Rhodopes.(10x)*



*E) Metamorphic lithic grain. Coarse grained muscovite-schist Central-Eastern Rhodopes.(10x)*



*F) Panoramic view of a typical quartzosefeldspathic sandstone with granitoids rock fragments, quartz and feldspars grains with diffuse carbonatic cementation. Central-Eastern Rhodopes.(5x)*

Plate 4. Main features of quartzolithic sandstones of deep-marine environment. Here are represented lithic grains of medium-high metamorphic grade (A-B-C-E), of sedimentary origin (D) and granitoids type (F). Central-Eastern and Southern Rhodopes. Magnification 10x, crossed nichols.

### 5.3.3 Volcaniclastic Petrofacies

This petrofacies is closely related with syncronous deposition during active volcanism as testified by the occurrence of Neo-volcanic grains, by the lack of Paleo-volcanic particles and by extremely low amounts of quartz and other nonvolcanic sand grains. From the modal analysis an appreciable correspondance with data from magmatic petrology literature has been found.

Volcaniclastic petrofacies is characterized by a dominance of lithic fragments as shown by detrital mode recalculations: $Qt_9F_{35}L_{56}$ (plate 5.a); $Qm_9F_{35}Lt_{56}$ (plate 5.b). Plagioclases are the most abudant between feldspars ($Qm_{20}K_{12}P_{68}$) (plate 5.c). Feldspars occur as neo-volcanic single crystals and within neo-volcanic rock fragments. Plagioclases are mostly calcic in composition, ranging between oligoclase and andesine ($An_{45-18}$), and occur as euhedral and zoned twinned. K-feldspars are dominantly represented by microcline and orthoclase as nonvolcanic detritus, and rarely, in Southern Rhodope sandstones by neovolcanic sanidine.

Phaneritic rock fragments consist dominantly of volcanic rock fragments ($Rg_0Rv_{97}Rm_3$) (plate 5.f) showing association of plagioclase and piroxene, and k-feldspars, quartz and biotite in minor concentration. Sometimes volcaniclastic sandstones show evidences of contamination represented by the presence of basement rock fragments such as amphibolite and schists.

Aphanitic lithic grains mainly consist of volcanic derived fragments ($Lm_4Lv_{94}Ls_2$) (plate 5.e) and subordinate metamorphic and sedimentary lithic fragments as shown by the occurrence of low-grade metamorphic grains (phyllite and mica-schists) and extrabasinal carbonates, respectively.

Volcanic lithic grains exhibit microlitic, vitric textures, lathwork (only in Central-Eastern Rhodopes sandstones) while the occurrence felsitic textures is limited ($Lvv_{43}Lvmi_{53}Lvl_4$; $Lvv_{40}Lvf_5Lvmi_{54}$, plate 6, a and b) to Southern Rhodopes volcaniclastic sandstones which largely include pumice and shards (plate 7.d-e).

There are many differences between Central and Southern Rhodope volcanism and for this reason the volcaniclastic sandstones of the two areas will be described separately.

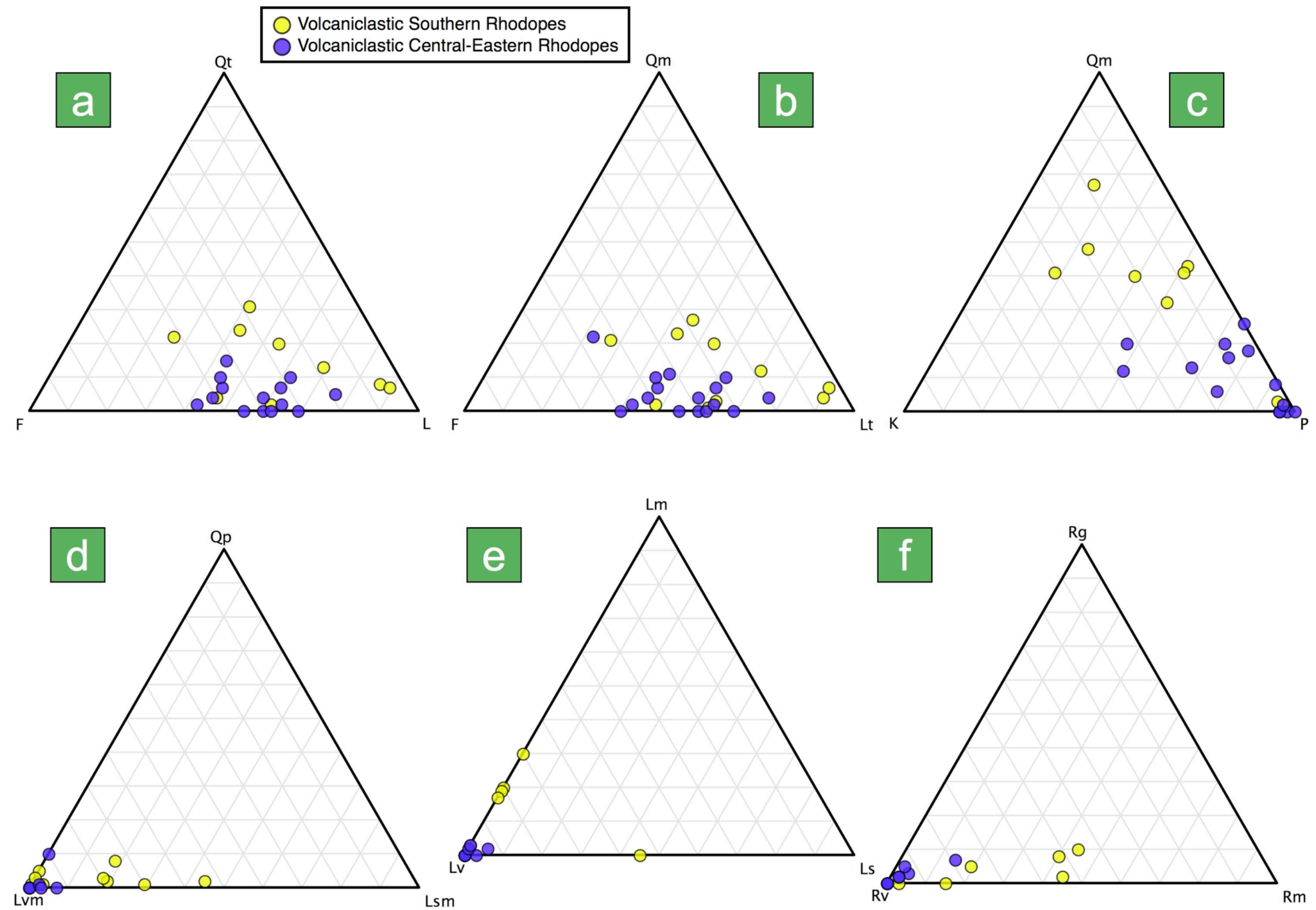



Plate 5. Ternary plots of detrital modes of volcaniclastic petrofacies of Rhodopes sandstones. A) Qt (total quartz); F (Feldspars); L (fine grained lithics – Qp); Qm (monocrystalline quartz); Lt (fine grained lithics + Qp); K (K-feldspars); P (Plagioclases); Qp (policrystalline quartz); Lvm (meta-volcanic lithic grains); Lsm (metasedimentary lithics); Lm (metamorphic lithics), Lv (volcanic lithics); Ls (sedimentary lithics), Rg (granitoid rocks); Rv (volcanic rocks); Rm (metamotphic rocks).

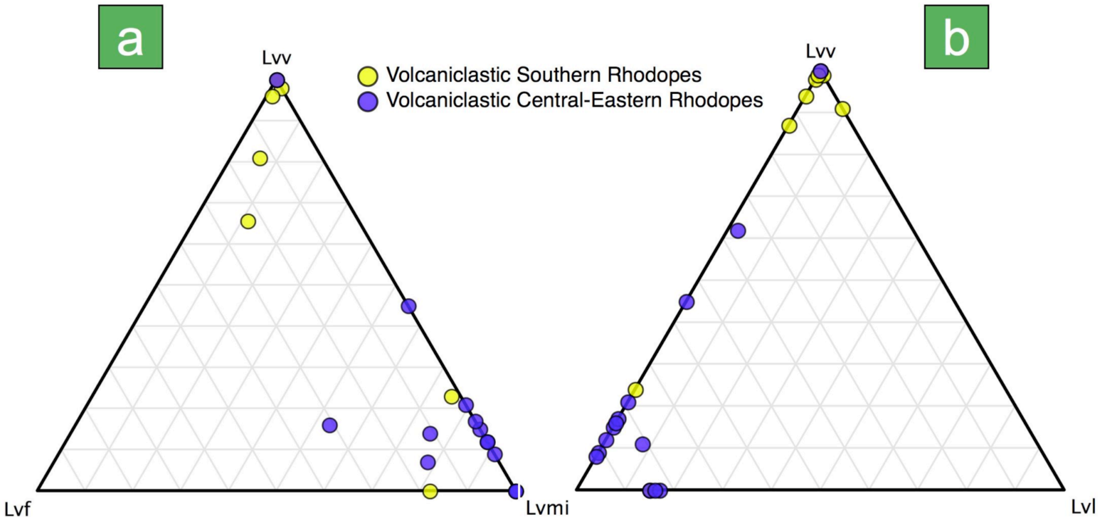
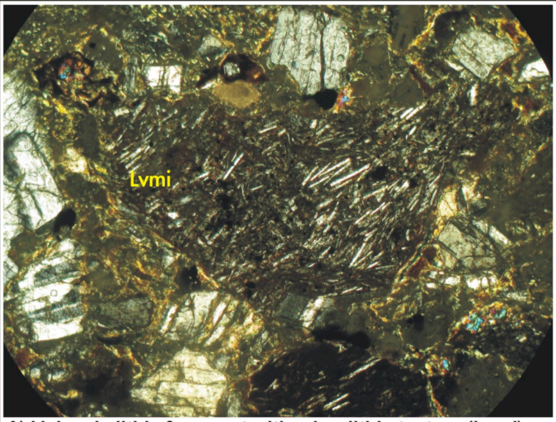
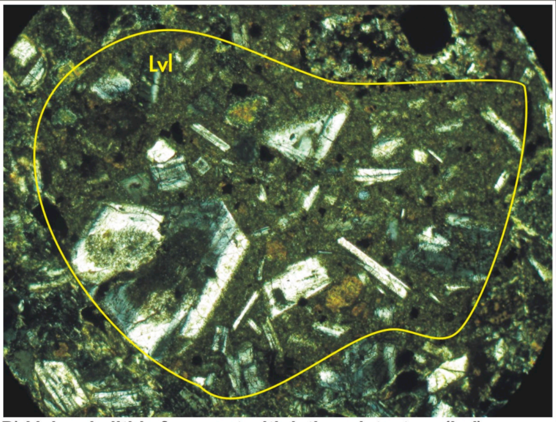


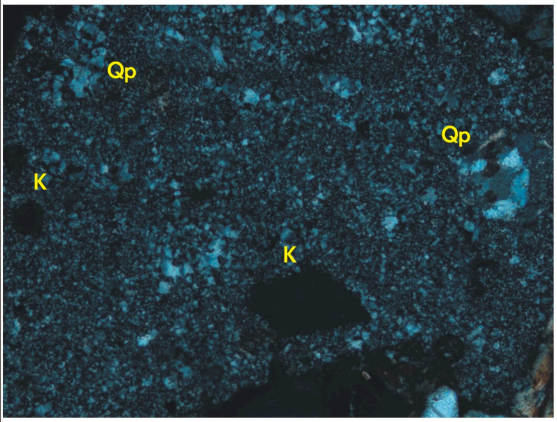

Plate 6. Ternary diagrams for volcanic lithic grains textures. Lvv: lithic volcanic with vitric texture; Lvf: lithic volcanic with felsic texture; Lvmi: lithic volcanic with microlithic texture; Lvl: lithic volcanic with lathwork texture. For explanation of the meaning of volcanic textures look to the text. These diagrams show that microlithic and vitric textures are the most abundant in Rhodopes volcaniclastic sandstones. There is a clear separation of volcanic lithic types, with the microlithic pratically limited to Central-Eastern Rhodopes sandstones, and the vitric to Southern Rhodopes sandstones.



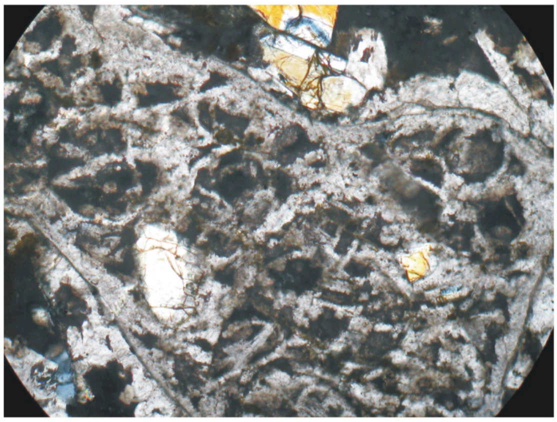

*A) Volcanic lithic fragment with microlithic texture (Lvmi). Central-Eastern Rhodopes (Karamfil). (10x)*




*B) Volacnic lithic fragment with lathwork texture (Lvl) including zonated plagioclases . Central-Eastern Rhodopes (Krumovgrad). (10x)*

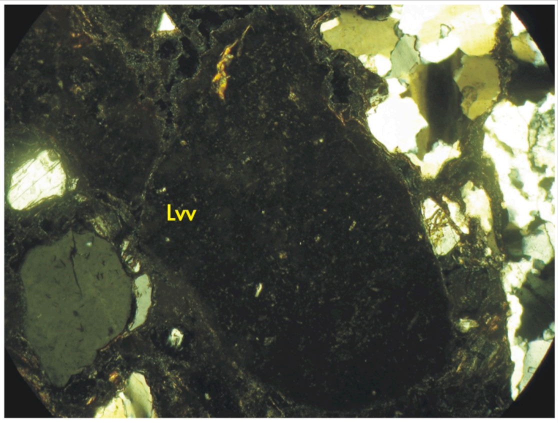



*C) Volcanic lithic grain with felsitic granular texture (Lvf). Southern Rhodopes (10x). Note policrystalline quartz (Qp) and small K-feldspars (K)*



*D) Pumice lithic fragment with inclusion of quartz grains. Southern Rhodopes (Loutros-Fere-Dadia). 10x, II nichols.*

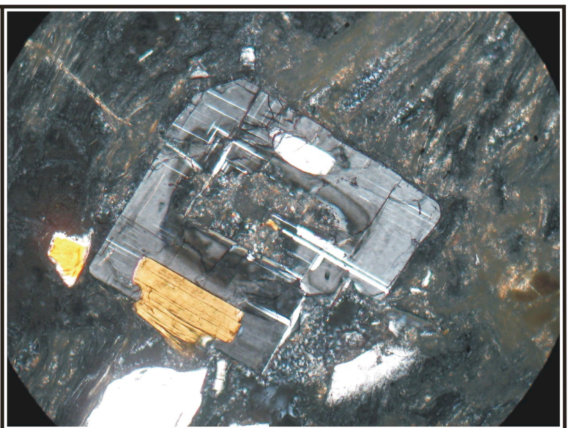

*E) Shards vitric fragments in volcaniclastic sandstones of Southern Rhodopes (Loutros-Fere-Dadia). 10x, II nichols.*



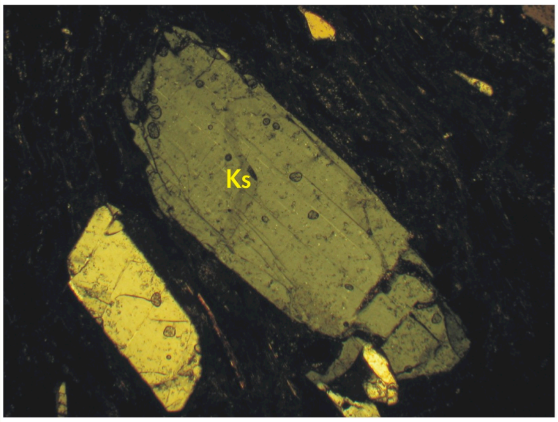

*F) Volcanic lithic grain with vitric texture (Lvv). Colorless groundmass. SouthernRhodopes (Alexandroupolis). (10x)*

Plate 7. Volcanic lithic grains of Rhodope sandstones. Here are represented the volcanic textures characteristics of analysed arenites. A) Microlithic; B)Lathwork; C) Felsitic granular; D) Pumice; E) Shards; F) Vitric texture. Magnification 10x; all pictures are in crossed nichols except for D and E.

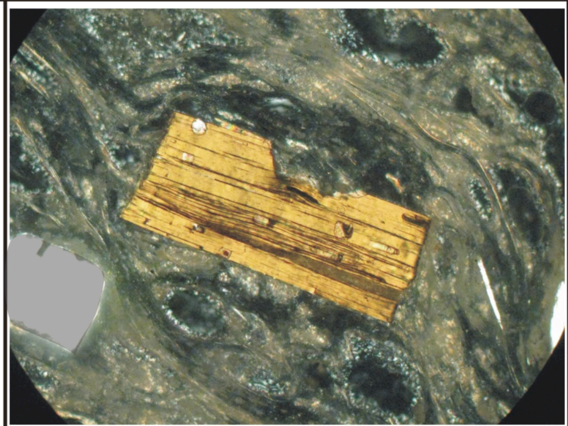
***A) Neo-volcanic plagioclase (euhedral) grain in a glass - welded groundmass. Note the strong zonation, typical of sin-eruptive volcanic plagioclases. Southern Rhodopes. (10x)***



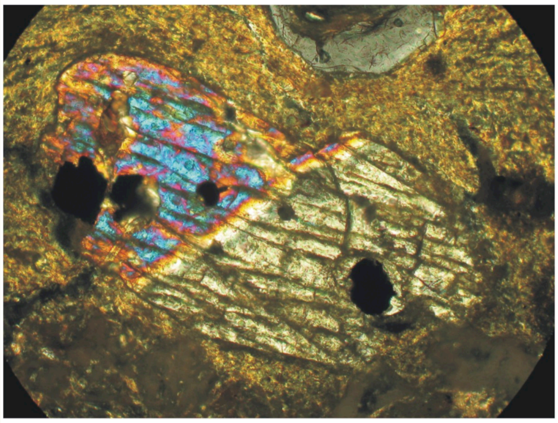
***B) Neo-volcanic plagioclase (euhedral) including biotite grain Note the strong zonation, to which correspond, at the center, alteration from zeolites minerals.Southern Rhodopes (10x)***



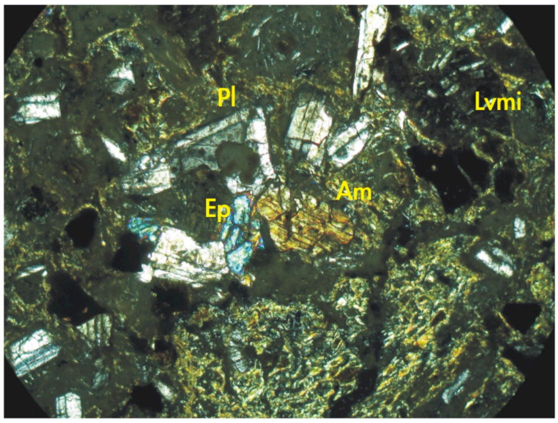

***C) Neo-volcanic K-feldspar (sanidine- Ks) in a glass-welded groundmass. Southern Rhodopes (10x)***



***D) Neo-volcanic biotite grain in a glass welded groundmass with zeolites and clay minerals.Southern Rhodopes. 10x.***

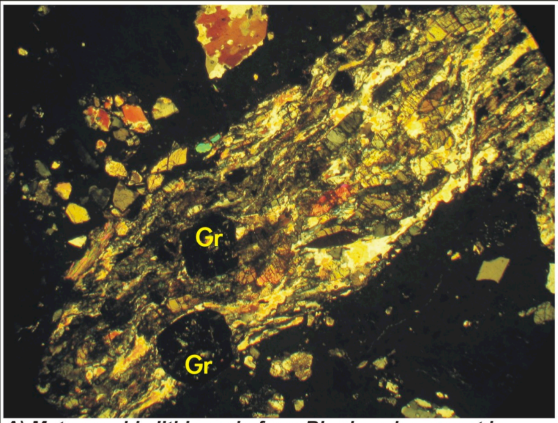


***E) Green amphibole (hornblende) grain of volcanic origin in a mixed volcaniclastic-siliclastic matrix. Central-Eastern Rhodopes (10x).***

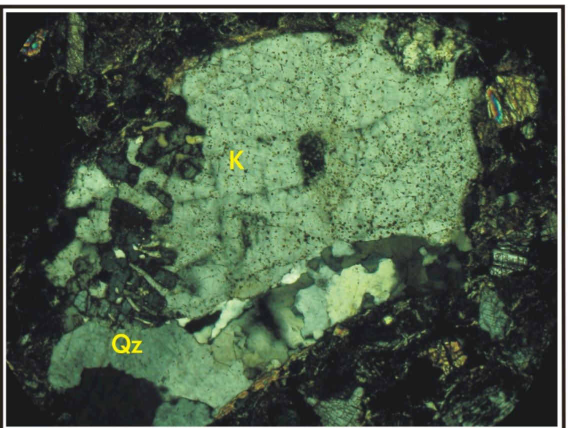



***F) Panoramic view of volcaniclastic sandstone of Central-Eastern Rhodopes. Pl: plagioclase; Ep: epidote; Am: amphibole; Lvmi: Lithic volcanic with microlithic texture (10x). Note the volcaniclastic matrix mixed with clay minerals. Central-Eastern Rhodopes. (10x).***

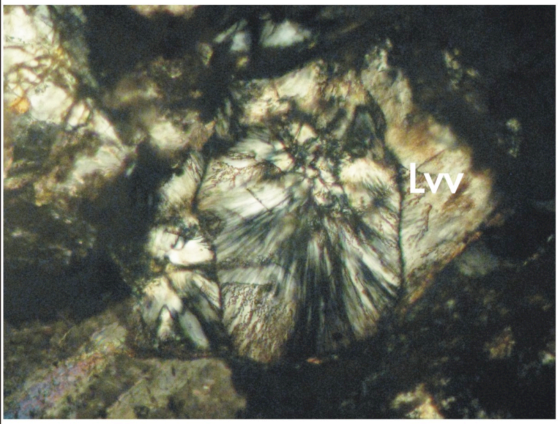
Plate 8. Neo-volcanic grains of Rhodopes sandstones. A and B: euhedral plagioclases; C) K-feldspar (sanidine); D) Phyillosilicate (primari biotite); E) amphibole (hornblende); F) general overview.



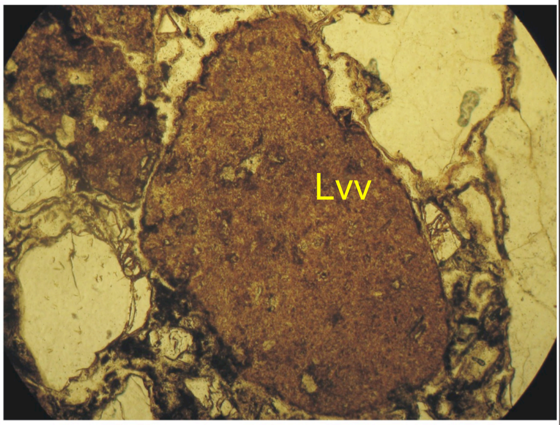

*A) Metamorphic lithic grain from Rhodope basement in volcaniclastic sandstone.Amphibolite with garnet (Gr). Southern Rhodopes. (10x)*



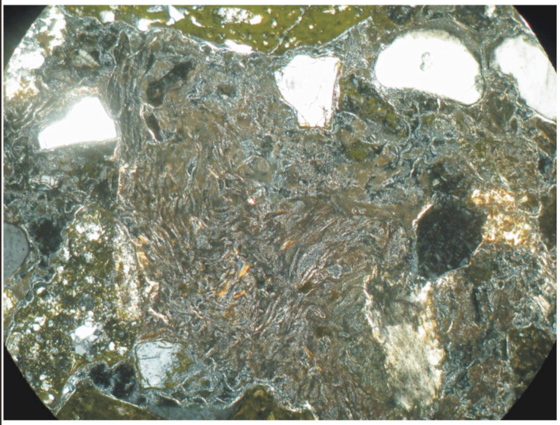

*B) Migmatitic gneiss with relict myrmekitic texture from plutonic protolith, in volcaniclastic sandstone. K: K-feldspar; Qz: quartz. Central-Eastern Rhodopes (10x)*



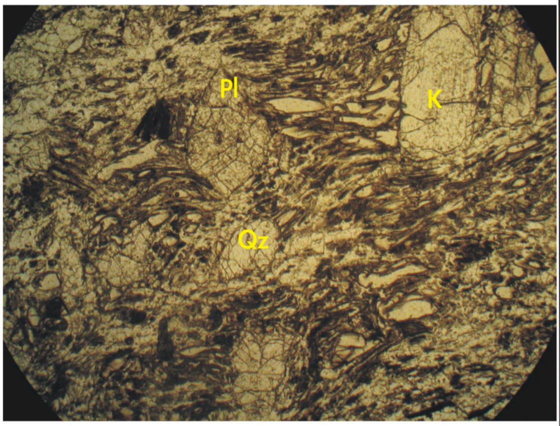

*C) Alteration by silica on volcanic lithic grain with vitric texture (Lvv). Southern Rhodopes. (10x)*




*D) Volcanic lithic grain with vitric texture (Lvv), orange coloured, testifying provenance from submarine eruptions. Southern Rhodopes. 10x.*



*E) Volcaniclastic matrix mixed with clay minerals. Southern Rhodopes. (10x).*




*F) Fluidal structures in volcaniclastic sandstones of Southern Rhodopes. K: K-feldspar; Pl: Plagioclase; Qz: quartz. (10x).*

Plate 9. Optical microscope pictures of non-volcanic related grains (A and B), volcanic glasses (C and D) and framework components (E and F). Volcaniclastic sandstones of Central-Eastern and Southern Rhodopes. Magnification 10x; all pictures are in crossed nichols, except for D and F.

#### *5.3.3.1 Southern Rhodopes volcaniclastic sandstones*

*Loutros-Fere-Dadia volcaniclastic sandstones*

Samples from this area can be classified as tuffaceous sandstones (Schmid, 1981) and are characterized by the extremely high content in shards and pumice. Texturally they show fluidal structures, typical of pyroclastic products (plate 9.f). Euhedral and zoned twinned plagioclases are neovolcanic (Critelli and Ingersoll, 1995) representing a deposition event syncronous with the volcanic activity. Quartz and K-feldspar are minor. Primary biotite (plate 8.d) has been recognized, it can be found as single crystal or within plagioclase (plate 8.b). Although single crystals occur frequently, pumice and shards constitute the most significant part of the framework (plate 7. d-e) Vitric volcanic fragments (Lvv) are generally colorless according with a felisc volcanic activity (plate 7.f). Fluidal structures, pumice and shards show recrystalization evidences by zeolites minerals.Samples from this area (SC-759; SC-760; SC 761) have been sampled from the bottom to the top of the succession. From a compositional point of view there are significant changes showed by the increasing of quartz and K-feldspar amounts to which correspond a decreasing of vitric volcanic lithic fragments, particularly of pumice and shards, and the appearance of felsitic volcanic lithic fragments, both granular and seriate (plate 7.c) type (Dickinson, 1970, Ingersoll and Cavazza, 1991). Moving upwards, samples testify evidences of contamination, as suggested by the appreciable amount of metamorphic lithic fragments rapresented by phyllite and epidote-schists. All samples include volcaniclastic matrix composed by ash and vitric fragments that upsection is mixed with clay minerals forming characteristics coatings on grains.

*Kirki – Esimi (Alexandroupolis) volcaniclastic sandstones*

These samples are characterized by the presence of welded glasses, closer to ignimbrites deposits, varying in content, co-existing with other volcanic lithic fragments, and dominantly with plagioclase. Even for samples of this area, plagioclases are neo-volcanic, with very low degree of roundness, appreciable dimensions and zonations. K-feldspar amount is variable, but generally occurs as orthoclase and sanidine. This samples includes abundant crystals of amphiboles, mostly rapresented by hornblende often showing their hacksaw typical alteration. Fe-oxides are common, sometimes present peculiar alteration (leucoxene). Quartz crystals are generally low in concentration and sometimes are included in neo-volcanic lithic fragments.

Between volcanic lithic grains, the ones having a vitric texture are the most represented. Felsitic granular and seriate textures are present in all samples according with a provenance from dacitic-rhyolitic volcanic areas (plate 7.c). Microlitic and lathwork textures occur, and their amount increase moving upward in the sampled succession. Even for the volcaniclastic samples from the Alexandroupolis area a compositional variation could be described. Moving from the bottom of the sedimentary succession towards the top of it, there is an increasment of the basic to intermediate textures, rapresented by microlithic and lathwork volcanic lithic fragments. Another positive variation derives from the size increasment of amphiboles. In samples from the lower part of the succession they occur only within the matrix while in the upper part reaches the sand grain-size. Lower sandstones are strongly related to the volcanic activity, as shown by their composition. Moving upsection there is an increasment of intrabasinal carbonate, rapresented by bioclasts of different types, and of extrabasinal carbonates such as micrite and bio-micrite.

The general increasing of extrabasinal carbonate grains and other non volcanic grains suggests that volcanic turbidites deposition at the bottom of the succession are syncronous with eruptive phases, and evolving up-section to products with a composition according to an inter-eruptive sedimentation in the upper part.

*Mesti-Petrotà volcaniclastic sandstones*

The volcaniclastic sandstones from this area show evidence of a strong contamination. Plagioclase content is constant, and occurs both as neo-volcanic or not, while quartz and K-feldspar occurrence is variable. The content in K-feldspars is significantly higher if compared with other areas, especially considering the presence of sanidine (plate 8.c). Concerning other NCE, these samples are characterized by a significative amount of amphiboles, mostly hornblende, epidotes and heavy minerals rapresented by tourmaline, zircon and sphene. Lithic fragments are mostly of volcanic origin, consisting of vitric lithic grains, including pumice and shards, and felsitic lithic grains with granular texture. Metamorphic lithic grains include amphibolite fragments and coarse-grained schists.

#### *5.3.3.2Central-Eastern Rhodopes volcaniclastic sandstones*

*Karamfil (Zvedzel volcano) volcaniclastic sandstones*

Samples from this area consist exclusively of neo-volcanic grains. Non-carbonate extrabasinal (NCE, Zuffa, 1980) grains are represented by solely plagioclase, quartz and K-feldspard. Plagioclase has calcic composition has shown by their extinction angle (18°-20°), ranging in composition between bytownite and labradorite. According with a neo-volcanic origin they are characterized by a preserved zonation and a very low roundness index. Heavy minerals content is generally high (up to 2%) and consist of pyroxenes and amphiboles and occasionally titanite. Volcanic lithic grains are mainly rapresented by microlitic textures and subordinately by lathwork and vitric textures. Pumices are well rapresented and often present evidences of alteration from clay minerals. Is very interesting to note that samples from three different volcaniclastic layers shows an increasing abundance of lathwork volcanic lithic grains and amphiboles moving upward, to younger layers. Upper samples are characterized by the occurrence of intrabasinal carbonates, principally algae and bioclast. The interstitial component consists of volcaniclastic matrix, sometimes including clay minerals.

*Kardjali volcaniclastic sandstones*

Volcaniclastic sandstones of Daijdovnitza area are typical of volcanism-related sediments deposited during inter-eruptive stages and could be related to the first Oligocene volcanic phase (ca. 30 Ma). Contamination is strong and rapresented by the occurrence of amphibolites (basement) and sedimentary lithic grains consisting of extrabasinal carbonates and rare sandstones and siltsones. Quartz and K-feldspar content is variable but generally high if compared to the other volcaniclastic petrofacies samples. Plagioclase occurs as single crystal, both, as neo-volcanic or not, and in volcanic and metamorphic rock fragments. Between lithic fragments the volcanic are dominant. Microlitic and lathwork textures are typical of these samples. Lathwork lithic fragments include principally phenocrysts of plagioclase and subordinately hornblende and pyroxenes. Volcanic lithic fragments are characterized by a yelllowish to brownish glassy groundmass suggesting a provenance from submarine eruptions. Interstitial component consists of mixed volcaniclastic matrix and siliciclastic rich in phyllosilicate matrix and less carbonate cements.

Contamination components increase from ancient to younger products.

*Southern Rhodopes (Krumovgrad area) volcaniclastic sandstones*

Here are described volcaniclastic sandstones of Southern Rhodopes, rapresentative of the Krumovgrad volcanic area where different volcanic centers, with mafic to intermediate volcanic rocks, developed in different phases, described before, between Upper Eocene and Oligocene. These samples are quite similar in composition with small varitations of quartz and K-feldspar content and different degree of contamination from non-volcanic detritus. Plagioclase shows a constant, very high concentration ($Qm_{20}$ $K_{12}$ $P_{68}$), and is mostly related to a volcanic provenance. Amphibole content is generally high, and occurs as syngle crystals or in volcanic and metamorphic rock fragments. Volcanic lithic fragments having lathwork and microlitic textures are the mostly abundant grain types. The groundmass of volcanic lithic fragments is often brown coloured suggesting frequent subacqueous eruptions in the area. Vitric and felsic textures are pratically absent. Interbasinal carbonate grains, consisting of bioclasts of different type and rare extrabasinal carbonate grains, are present in volcaniclastic sandstones of Krumovgrad area. Interstitial component consists of impure volcaniclastic/siliciclastic/carbonate matrix and pore-filling carbonate cement.

# GEOCHEMISTRY

## *6.1 Introduction to the geochemical approach*

Since the half of the past century provenance studies on sedimentary rocks have been associated with sandstones composition obtained through different point counting techniques (Gazzi,1966; Dickinson, 1970; Ingersoll et al., 1984). Relatively recent studies (Crook, 1974; Bathia, 1983; Roser and Korsch, 1988) demonstrated that sedimentary geochemistry is a powerful tool to reconstruct geodynamical settings of clastic sedimentary basins. Integration of erosion resistant immobile trace and rare earth elements into geochemical evaluations improves the interpretation of the provenance signals (Bathia and Crook, 1986; McLennan, 1989; Floyd et al., 1991; McLennan et al., 1993).

The combined use, of petrographic and geochemical approaches, increases the number of possible information to describe the sedimentary processes and the provenance of sedimentary rocks. Integration of data allows to get a more detailed characterization of weathering, diagenesis, sorting and recycling effects and to obtain a wide range of information on the source area regarding the rock types, the terrane type, terrane identification, provenance age and crust/mantle character.

One hundred thirty-six samples have been studied using geochemical analysis, including nine samples excluded by the petrographic analysis due to a fine grain-size or a volcanic provenance. Data obtained from geochemistry improved the number of informations and perfectly suites with data from petrographic analysis.

### *6.2 Methods*

#### *6.2.1 Major elements*

Fresh rock samples were reduced by a jaw crusher to a grain size < 2cm. A representative fraction of samples has been powdered to ~ 60μm using an agate jar mill. Chemical analyses were performed on powders of selected arenitic samples. Loss on Ignition (LOI) has been determined gravimetrically on pre-heated powders (110°) after 1 hour ignition at 1000° in a microwave oven (MAS 300). Major elements have been determined by X-Ray fluorescence (ARL 9400 XP, operating at Dipartimento di Scienze della Terra, Università di Pisa) on a glass beads following the procedure of Tamponi et al. (2003). Fused beads were prepared after ignited powders in order to avoid sulfide minerals leading to the corrosion of the platinum crucible during the flux melting.

XRF major element concentrations were then corrected to eliminate CaO not deriving from terrigenous sources. The correction for calcite content was based on the assumption that the plagioclase composition is usually albitic and Ca is mainly hosted in the carbonate fraction of sediments. The correction consisted of subtracting from major element concentrations all the CaO of the samples, except from that necessary to saturate phosphorous in apatite (the total normalized to 100 wt%). Total iron is expressed as $Fe_2O_3$.

#### *6.2.2 Trace elements*

Trace elements have been determined by X-Ray fluorescence using powder pellets (with the same equipment used for major elements) and achieved by a full matrix effect correction, following the method purposed by Leoni and Saitta (1976).

### *6.3 Theory at the base of compositional data analysis*

Compositional data consist of vector whose components are the proportion or percentages of some whole (Aitchinson, “A concise guide…”). Their peculiarity is that their sum is constrained to the be some constant, equal to 1 for proportions, 100 for percentages or possibly some other constant *c* for other situations such as parts per million (ppm) in trace element compositions.

This technique is based on the concept that in a general data set, expressing a composition of a certain number of samples, there are appreciable variations.

A generic composition $[x_1 \ x_2....x_D]$, with *D* parts with label 1,2,…,*D* and components $x_1 \ x_2....x_D$ if expressed as percentages the components will sum constantly to 100.

Since compositional data provide information only about the relative magnitudes of the parts, not their absolute values, then the information provided is essentially about ratios of the components (Aitchinson….). There is a one-to-one correspondence between compositions and a complete set of ratios.

Let’s consider a relationship like this:

$$\mathrm{var}\{\log(x_i / x_j)\} = \mathrm{var}\{\log(x_j / x_i)\}$$

and considering that there is a one-to-one correspondence between composition and the full set of log-ratios

$$[y_1 \ . \ . \ . \ y_{D-1}] = [\log(x_1 / x_d) \ . \ . \ . \ \log(x_{D-1} / x_D)]$$

with inverse

$$[x_1 \ x_2....x_D] = [\exp(y_1) \ . \ . \ . \ . \ \exp(y_{D-1}) \ 1] / \{\exp(y_1) + . \ . \ . \ . + \exp(y_{D-1}) + 1\}$$

all the problems related to composition can be expressed in terms of log-ratios and vice versa.

The characterization of these variations represents a powerful tool to recognize specific compositional associations. The interpretations of these associations are essentially in determining processes controlling sandstone composition.

### *6.4 Component log-ratio transformation*

The approach developed by Aitchison is built on the use of log-ratio between the data set of a composition, taking in account that the main information in compositional data is given by the relative variations and not by the absolute values. Transformations of compositional data based on the log-ratio approach are the *additive log-ratio* (alr) transformations and the *centered log-ratio* (clr) transformations introduced by Aitchison (1982) and the *isometric* log-ratio transformations of Egozcue et al. (2003). In this work the centered log-ratio transformation has been applied. For a 3 part composition like **x**=[75,18,7] the representation could be wrote as a 3 component vector fot the *clr* coefficients:

$$clr(\mathrm{x}) = clr[75,18,7] = \left[\ln\frac{75}{(75\times15\times3)^{1/3}}, \ln\frac{18}{(75\times15\times3)^{1/3}}, \ln\frac{7}{(75\times15\times3)^{1/3}}\right] = [1{,}26, -0{,}16, -1{,}1]$$

The *clr* coefficients, has been obtained dividing each component of composition by the geometric mean and taking the logarithm of the ratio. They show numerous advantages such as the isometry and the distance calculation that could be done using the euclidean geometry. This transformation is used in producing biplots and in data multivariate explorative analysis (i.e. principal component analysis, cluster analysis, etc.)

A Biplot is a graphical representation of the information in an *n* x *p* data matrix (Everitt & Dunn ,2001). This technique allows the representation given by the variables as indicated by their variances and covariances and the relationship between individuals as indicated by particular measures of inter-individual distance. The technique is completely described in Gower and Hand (1996). The use of biplot for compositional data has been introduced by Aitchinson (1990b) in order to get an approximate picture of the whole compositional variability, not just of the dependence structure, but also the relationship of individual case to the compositional parts Aitchinson (1997). The biplot consists of an *origin* (Fig.) representing the centre of the compositional data set, a *vertex* represented by the end of the arrow. The line connecting the origin with the vertex is called *ray* and the join of two vertices *link*.

### *6.5 Sandstone geochemistry*

Major and trace element compositions of quartzolithic, quartzose-feldspathic and volcaniclastic sandstones, are reported in tab (1;2;3;4) appendix 2.
According to the major element compositions most of the analyzed samples result to be classified as wacke and subordinately arkose and litharenite (fig.6.1).

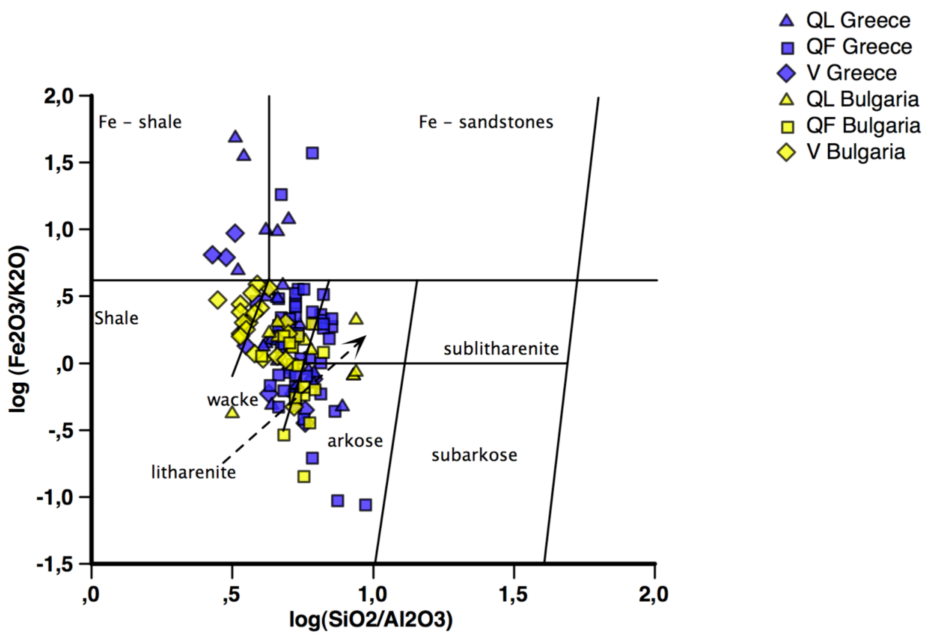



Fig.6.1Herron sandstones classification

Confirming the petrographic data there are no indications for mineralogic maturation processes during sand development, suggesting rapid erosion and short sediment transport. High values of the $Fe_2O_3/K_2O$ ratio for quartzolithic sandstones are related to extremely oxidated siliciclastic matrix. For volcaniclastic samples this high ratios could be explained through the appreciable amount of primary volcanic biotite.

The general high values of Na/K molar ratios demonstrate, according to petrography, the dominance of sodic plagioclase among feldspars. There are few samples from Avdira succession showing anomalies for Na/K ratio due to extremely low content in K.

Major elements and LOI reflects the large range of mixing between silica/silicate phases and carbonate phases in sandstones (Von Eynatten, 2003).

The calcite dilution is reflected by the $SiO_2$ content that shows a negative correlation with CaO, ranging from 33% to 0.5% and from 25% to 85% respectively (fig.6.2). The clear positive correlation between CaO and LOI suggests that CaO is strongly related to carbonates, as results of the separation of $CaCO_3$ in CaO and $CO_2$ (included in LOI) generated during the fusion of the samples.

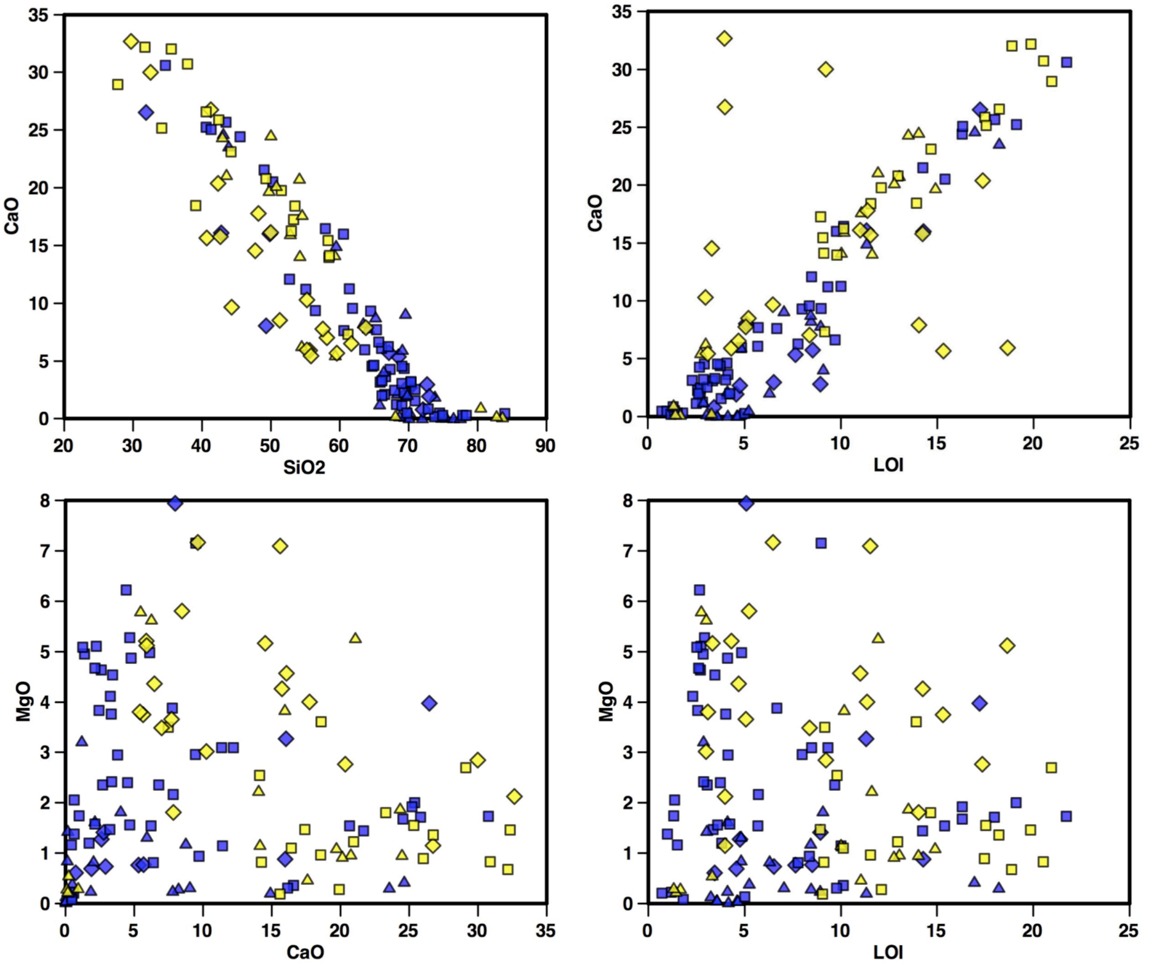



Fig. 6.2 Bivariate variation diagrams for major element oxides CaO, $SiO_2$ , MgO and loss on ignition (LOI)

## *6.6 Weathering and recycling*

The influence of climate and relief on the eroded and transported terrigenous detritus, responsible in determining sandstones characteristics, is known but difficult to quantify.

The chemical index of alteration (CIA) has been introduced by Nesbitt and Young (1982) and calculated using molar proportions of aluminium versus alkalis plus calcium in silicates (CaO*) and aluminium multiplied with 100, in order to avoid all climatically controlled processes.

$$C.I.A. = \frac{Al_2O_3}{(Al_2O_3 + CaO^* + Na_2O + K_2O)} * 100$$

Carbonates clast content is low for Southern Rhodopes sandstones, while in Central and Eastern Rhodopes sandstones a significative increasing has been recognized. The amount of carbonate cements is variable, but considering the whole number of samples is high, representing in Central-Eastern Rhodopes sandstones the most important among interstitial components. The CIA values (mean 54) indicate that weathering was not so intense as shown by the A-CN-K ternary diagram (fig. 6.3). Quartzolithic sandstones of Southern Rhodopes represent the most altered samples, where an enrichment trend in $Al_2O_3$ from older to younger products is described in Fig 6.4. This trend reflects a first enrichment towards the A-CN side and a K-metasomatism effects for the youngest sandstones. An opposite trend is documented For Central-Eastern Rhodope sandstones. Older products are collocated close to the $Al_2O_3$ apex, while younger sediments move gradually towards the A-CN/un-weathered side. This pattern maybe interpreted as an effect of an increase of the tectonic uplift and therefore of an erosive process with the exhumation of the deeper levels of the continental crust which are also more mafic and fresher. This suggests that source areas uplift was not constant in time, but probably characterized by a first uplift phase, followed by a steady state phase, probably associated whit a warm and wet climate, that kept the source rocks in favourable weathering conditions. The trend towards illite diverges from the ideal feldspar weathering line, which parallels the Al-Ca+Na (Nesbitt & Young 1984), due to syn- or post-depositional K-enrichment in clay fraction (Fedo *et al.* 1995) suggests significant K-metasomatism of clay minerals (Fedo *et al.* 1997, Roser *et al*. 2002). High

Ca+Na values with low Al and K are possibly an additional input of Ca and Na due to metasomatism. Quartzosefeldspathic sandstones from Southern Rhodopes shows different degree of weathering for different source areas (fig.6.4 b) without presenting particular evolutionary trends related to the age of analyzed samples.

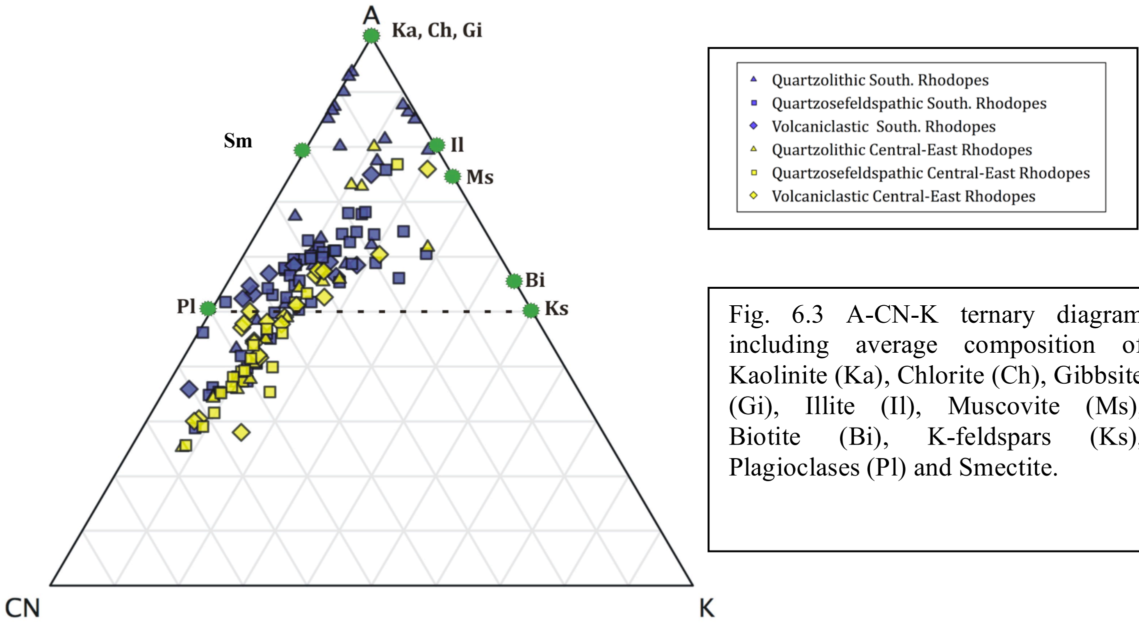



Fig. 6.3 A-CN-K ternary diagram including average composition of Kaolinite (Ka), Chlorite (Ch), Gibbsite (Gi), Illite (Il), Muscovite (Ms), Biotite (Bi), K-feldspars (Ks), Plagioclases (Pl) and Smectite.

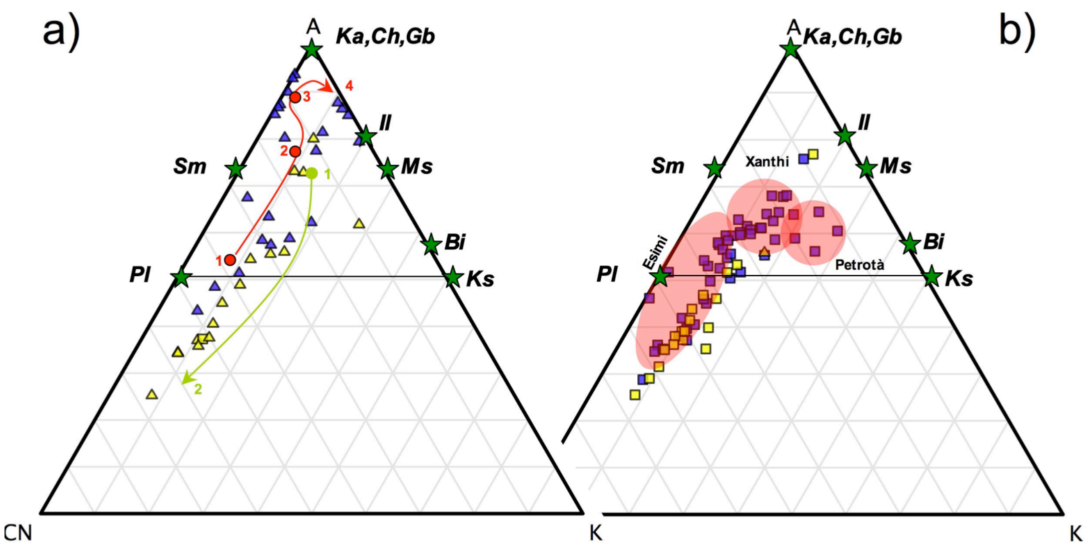
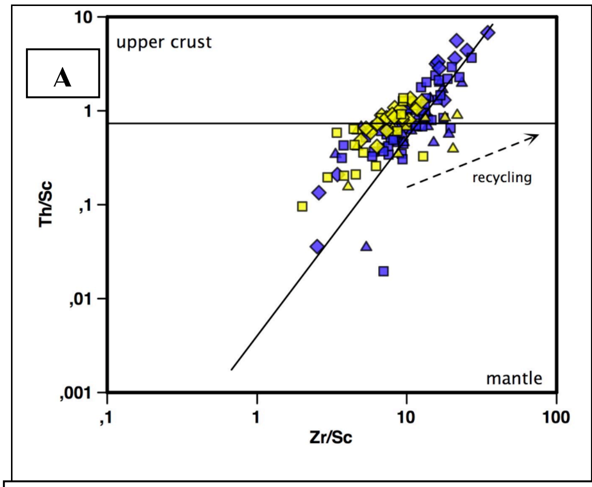



Fig.6.4 a) A-CN-K diagram for quartzolithic sandstones. Red curve indicates evolutionary trend from oldest (1) to youngest (4) products of Southern Rhodopes sandstones. b) A-CN-K diagram for quartzosefeldspathic sandstones. Green curve evidences an opposite evolutionary trend for Central-Eastern Rhodopes sandstones. Kaolinite (Ka), Chlorite (Ch), Gibbsite (Gi), Illite (Il), Muscovite (Ms), Biotite (Bi), K-feldspars (Ks), Plagioclases (Pl) and Smectite.

ycle reworking of same sediment material cannot be excluded by looking at major elements alone. According to Mc Lennan et al (1993), Th/Sc and Zr/Sc can be used to evaluate multi-cycle effects. Fig.6.5 shows no evidence of recycling for Rhodope sandstones.

According to Von Eynatten (2003), possible reworking effects are excluded by low values of the Cr/Ni ratios with no evidence or trends of its increasing.



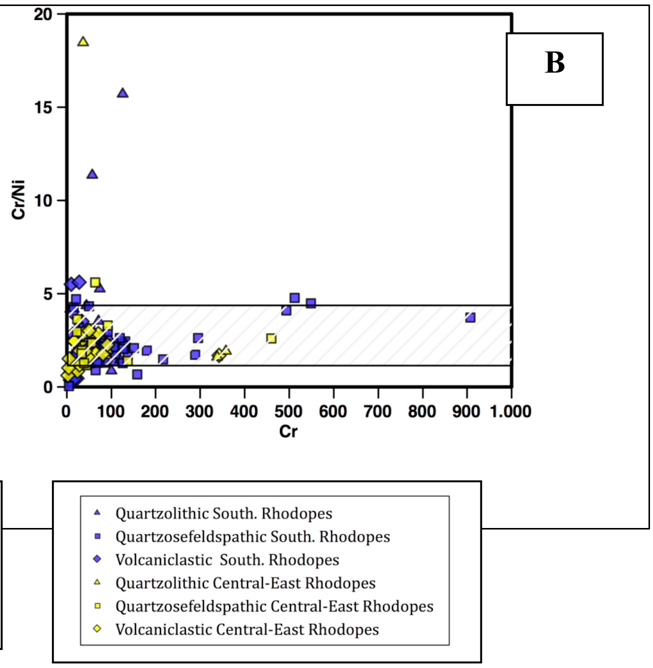




Fig 6.5. a) Zr/Sc vs Th/Sc diagram (Mc Lennan et al., 1993) and b) Cr vs Cr/Ni (Von Eynatten, 2003). Both diagrams evidences the absence of recycling effect.

### *6.7 Geodynamic setting of Central-Eastern and Southern Rhodopes basins*

The reconstruction of paleogeography is of primary importance in characterizing basin evolutions and can't be apart from the knowledge of the tectonic setting in which they developed.

Many authors pointed out the efficacy in using major element geochemistry of sedimentary rocks to infer tectonic setting based on discrimination diagrams (Bhatia, 1983; Roser and Korsch, 1986). On the other side, a lot of authors figured out the limits in using geochemistry to interpret tectonic settings (Van de Kamp and Leake, 1985; Nesbitt and Young,1989; Milodowski and Zalasiewicz, 1991).

As a result of this, discrimination of tectonic setting diagrams are largely used, sometimes evidencing important mistakes, demonstrating that supposed tectonic setting, from this geochemical discrimination diagrams, were inconsistent with the inferred tectonic reconstructions from ancient terranes (Toulkeridis et al., 1989; Haughton, 1988; Holail and Moghazi, 1998).

Armstrong and Verma (2005) tested the most used tectonic setting discrimination diagrams determining the correspondance to the already known tectonic settings. Percentages of success are, in general, extremely low. They used the diagrams from Bathia (1983) and Roser and Korsch (1986). The highest success is rapresented by the Roser and Korsch (1986) diagram, that shows a good match between the known tectonic setting and the inferred settings.

The southern euro-asiatic margin is widely and obviously considered as an active margin involving terranes originated in an oceanic island arc tectonic setting, here represented by the Variegated Complex (see Haydoutov 2001), described in chapters 2 and 3. Plotting the geochemical data from Rhodope sandstones is possible to recognize a good match with the known/inferred tectonic setting, with < 10% of samples falling out of the supposed field (fig.6.6). Plotted sandstone are equally distributed between oceanic island arc (OIA) and active margin (AI) fields. At least, is necessary to remark that quartzolithic sandstones falling in the passive margin field (PM) are the same showing important evidences of a provenance from weathered source rocks described in fig. 6.3 and 6.4. If considering weathering, as a condition favoured by the absence of uplift and low erosion ratios is right, is intelligible to compare this conditions according with a passive margin tectonic setting.

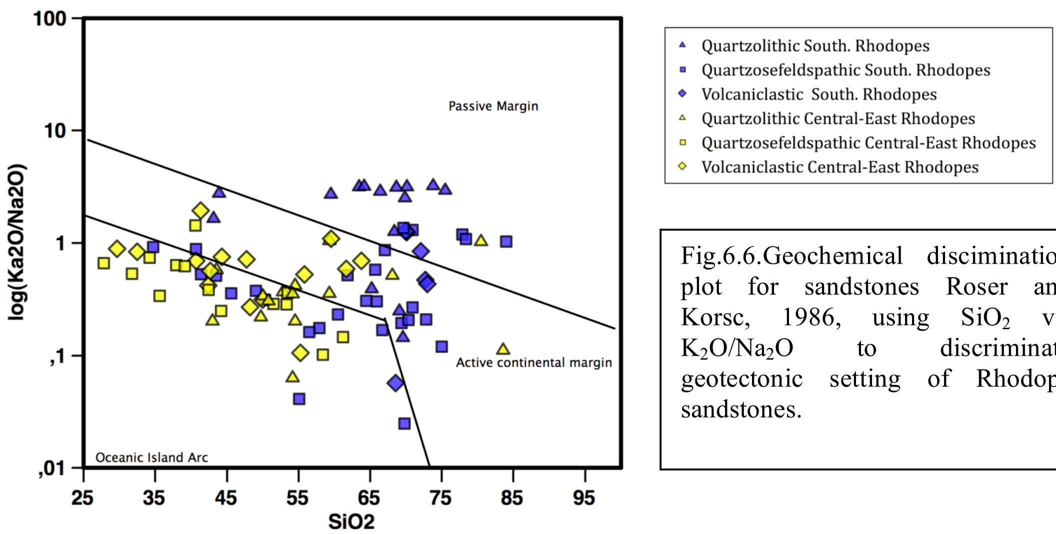



Fig.6.6.Geochemical discimination plot for sandstones Roser and Korsc, 1986, using $SiO_2$ vs. $K_2O/Na_2O$ to discriminate geotectonic setting of Rhodope sandstones.

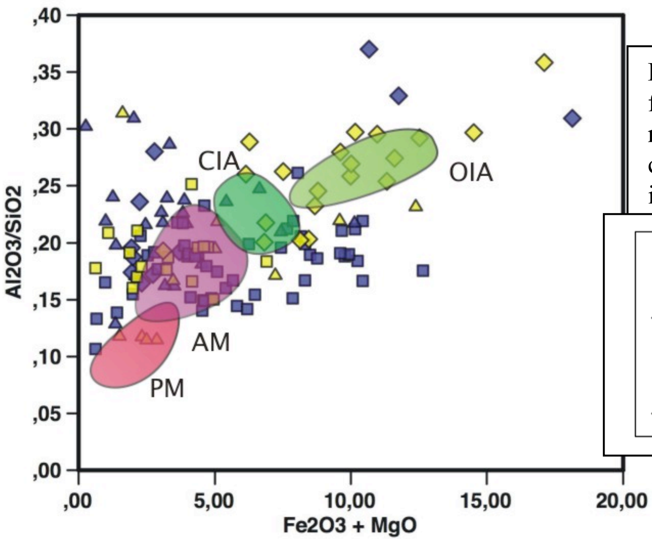



Fig. 6.7. $Al_2O_3/SiO_2$ vs $Fe_2O_3$+MgO, from (Bathia, 1983). PM=passive margin; AM= active margin; CIA= continental island arc; OIA= oceani island arc.

Same indications are given by the $Al_2O_3/SiO_2$ vs $Fe_2O_3$+MgO (Bathia, 1983) in fig.6.7. In this diagram volcaniclastic sandstones from Central-Eastern Rhodopes are better characterized, with most of them falling in the oceanic island arc field.

Using immobile trace elements ratios is helpful in order to avoid the overlapping of provenance signals, since their ratios are not vulnerable to post and pre-depositional processes (Floyd et al., 1991, Mc Lennan et al., 1993).

The characterization of two different sources mixing can still be modelled, but describe the interplay of several sources is difficult.

Using ferrous trace elements ratios is useful to recognize significative components of ultramafic units in the source area. In the studied area the ultramafic complex is represented by the Variegated complex (Haydoutov, 2001) in which small spots of a dismembered ophiolite complex are exposed both, in Central-Eastern and Southern Rhodopes. Petrographically, clear evidences of an ophiolite contribute are present in 4 sandstones, of continental environments, of Central Rhodopes overlying a serpentinite basement. Y/Ni vs. Cr/V (McLennan et al., 1993) is largely used to identify an ophiolite source and its proximity (fig.6.8). The Cr/V ratio expresses the Cr enrichment over the general level of ferrous elements. V and Ni express the relative abundance of ferromagnesian elements, showing high values for mafic-ultramafic sources. It is nice to describe the presence of two different source areas, ultramafic and felsic, evidencing a trend for both, the quartzolithic and the quartzose-feldspathic sandstones of Southern Rhodopes. These samples show low Y/Ni ratios and belong to the continental and deep-marine succession of the Esimi-Leptokaria area representing the older basin of the whole Rhodope area. According to the geodynamic evolution described in the previous chapters an ultramafic source, represented by the Variegated complex can be supposed as source area for the older products.

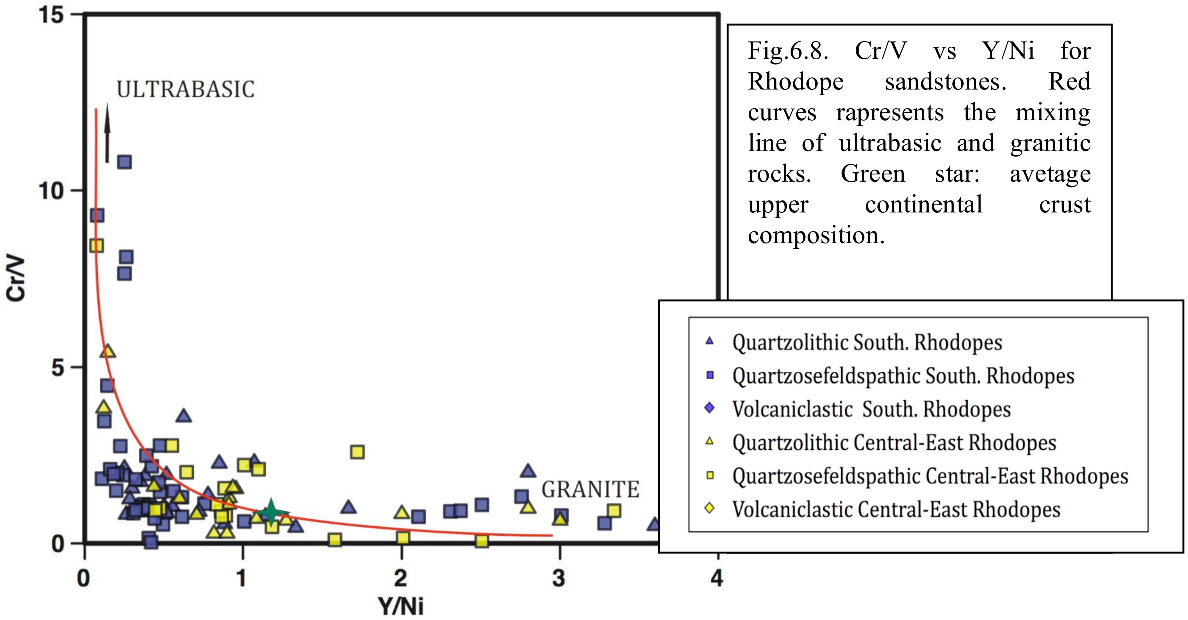



Fig.6.8. Cr/V vs Y/Ni for Rhodope sandstones. Red curves rapresents the mixing line of ultrabasic and granitic rocks. Green star: avetage upper continental crust composition.

Younger products are located in the major mixing area, characterized by low Cr/V and Y/Ni ratios. Quartzolithic samples of Central Rhodopes, including serpentinite lithic fragments, show low values of Y/Ni ratios and high values of Cr/V according to an ophiolite affinity. Volcaniclastic samples have been excluded because of the low-potential discrimination of Y, that is known to be an immobile element concentrating in residual phases of fractionating processes during melting / crystallization phases.

In terms of discrimination of tectonic settings the use of trace element has been widely adopted. Many diagrams have been proposed in literature (Bathia, 1985; Bathia & Crook, 1986; Mc Lennan; 1993; Floyd et al., 1991; Taylor and Mc Lennan., 1985) but the given indications must be considered carefully.

La-Th-Sc and Th-Sc-Zr/10 ternary diagram from Bathia & Crook (1986) shows that most of the samples fall in the continental island arc (CIA) and oceanic island arc (OIA) fields with minor or zero samples included in the passive margin field (fig 6.9).

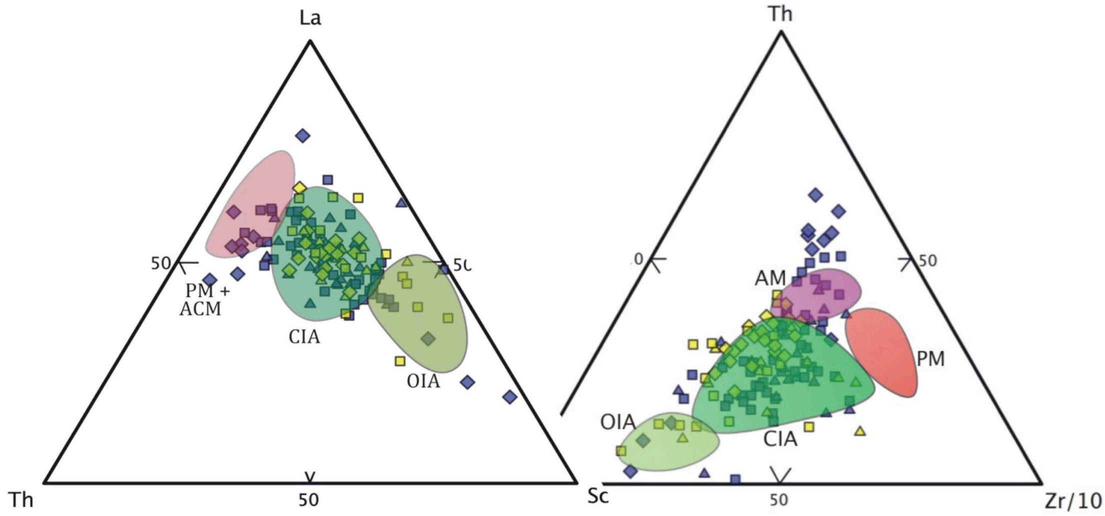



Fig. 6.9. La-Th-Sc and Th-Sc-Zr/10 ternary diagrams (Bathia & Crook, 1986) for Rhodope sandstones. PM = passive margin; ACM = active continental margin; ; AM= active margin; CIA = continental island arc; OIA = oceanic island arc.

These diagrams show a separation between Central-Eastern and Southern Rhodopes samples for the volcaniclastic samples. The Central-Eastern Rhodopes samples are positioned in the CIA field, while the Southern Rhodopes samples fall in the AM (AM+PM) field. Quartzosefeldspathic sandstones show a similar behaviour, and are practically concentrated in the CIA field.

There is a good match between the inferred and the known tectonic setting, and it is necessary to remark the correspondences between the two represented diagrams with the other, in which major elements are used. Volcaniclastic samples are in the same fields in both diagram groups and the same happens for the quartzosefeldspathic sandstones. There are some problem for the quartzolithic sandstones, because they showi evidences of weathering. Using trace elements they collocates close to the border of CIA and PM – PM+ACM fields.

The major element diagrams show that, quartzolithic samples principally fall in the PM field (Roser and Korsch, 1986') and widespread in all fields using $Al_2O_3/SiO_2$ vs $Fe_2O_3$+MgO diagram.

### *6.8 Biplots interpretation*

There are three sources of information within a biplot: the information contained in the position and distance among the points, the length of (biplot-) axes and angles between them and thirdly the position of points corresponding to the axes.

Interpreting points : With the points the same arguments work as in any other point-based plot such as dot plot or scatterplot: it is assumed that points lying close by have similar values. Therefore interesting graphical elements in a biplot are the same as in a dotplot or scatterplot: gaps, groups and outliers are easy to recognize.

In a biplot the lenghts of a line correspond to the variance of the corresponding variables, and the angles between them represents the size of their correlation, small angles corresponding to high correlations. In case of coinciding vertices this means that the ratio between such elements can be assumed as constant (fig.6.10a). Having a group of collinear rays and parallel links the sub-composition has a one-dimensional biplot and consequentially a one-dimensional variability. The parallelism between rays is representative of the dependence of the corresponding variables. The dependence is of direct type if the angle between the variable is 0°, and of inverse type for 180° angles (fig.6.10b). An orthogonal set of parallel links indicates an independence of the associated sub-compositions (fig.10c). Having three variables, positioned at 120° degrees respectively, they defines a ternary diagram where the variability of the data set is very high. This suggests that these variables are controlled by independent processes (Tolosana-Delgado et al., 2005).

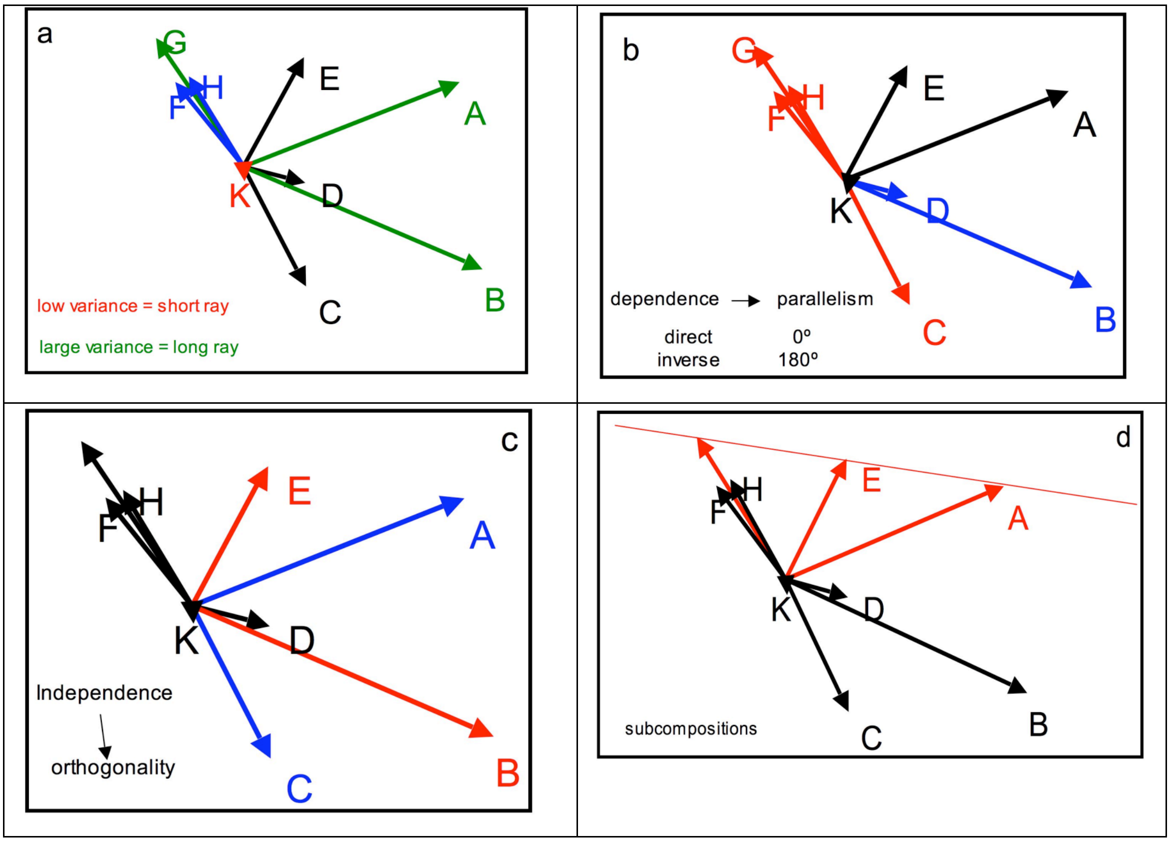



Fig. 6.10. Key steps for interpretation of biplots. a) variance of correspondent element; b) dependance (direct or inverse) of each element from the others; c) independence between elements in case of orthogonality; d) how to chose sub-compositions (3 elements on a line)

### *6.9 Results of compositional data analysis*

On the base of petrographyc analysis a relationship between sandstone composition and depositional environment has been documented. Basing on these data has been chosen to perform biplots for each group of sandstones peculiar of specific environment. Major and trace elements have been evaluated together and then displayed in function of their meaning.

#### *6.9.1 Quartzolithic sandstones of continental environment*

The principal component analysis of quartzolithic sandstones evidenced different trends and behaviours for arenites of different areas. In this case, only the first and the second principal components have been considered. They explain together the 78 % of the total variability.

From a first look it’s possible to see a clear separation between Central – Eastern Rhodope and Southern Rhodopes sandstones (fig 6.11). The first, groups in function of the calcite content (right-lower part of the biplot)mainly related to the presence of carbonate cements and extrabasinal carbonates lithic fragments. Regarding the Southern Rhodopes sandstones is clear that these are separated in two main groups. The first, in the upper part of the biplot, correspond to arenites located at the base of continental successions. This part of the biplot is characterized by a group of variables, represented by the association of Cr, $Fe_2O_3$ and Ni, suggesting a provenance from a mafic source area.

The samples from the upper parts of the continental successions are grouped in the lower-left part of the biplot, characterized by the association of felsic variables such as Th, Zr and La.

These data suggest that the beginning of sedimentation in the area is characterized by a mafic supply, becoming more felsic in time.

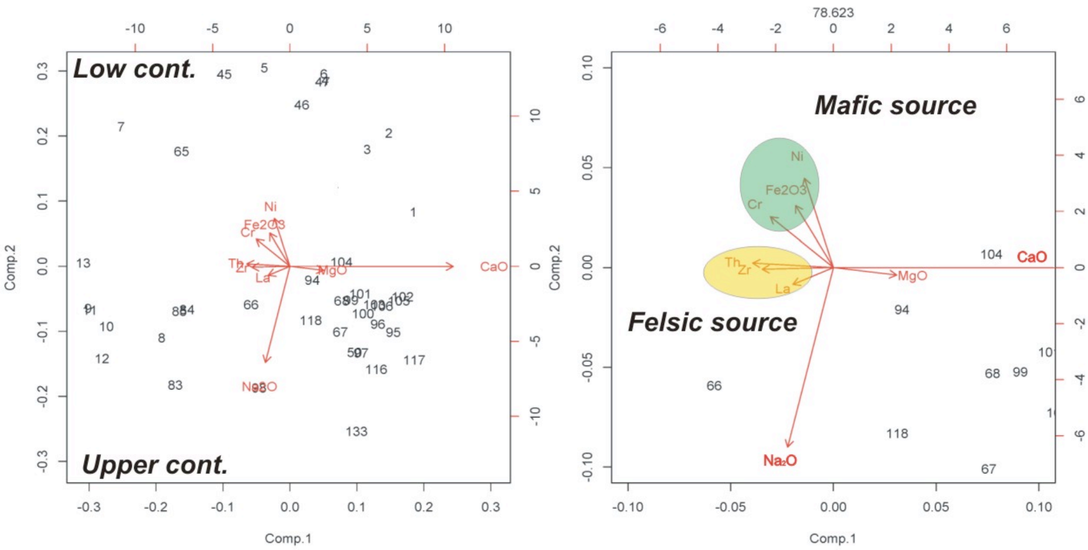



Fig. 6.11. Biplots for continental sandstones of Central-Eastern and Southern Rhodopes Left biplot is a zoom of the one to the right and offers a better view of mafic and felsic element associations. In green circle: Ni, Cr and $Fe_2O_3$; in yellow circle: Th, Zr and La.

*6.9.2 Quartzosefeldspathic sandstones of deep-marine environment*

Deep marine sandstones have been evaluated considering the first and the second principal components, here explaining the 77.5 % of the total variability. Observations on biplots (fig. 6.12) of quartzosefeldspathic (deep marine environment)

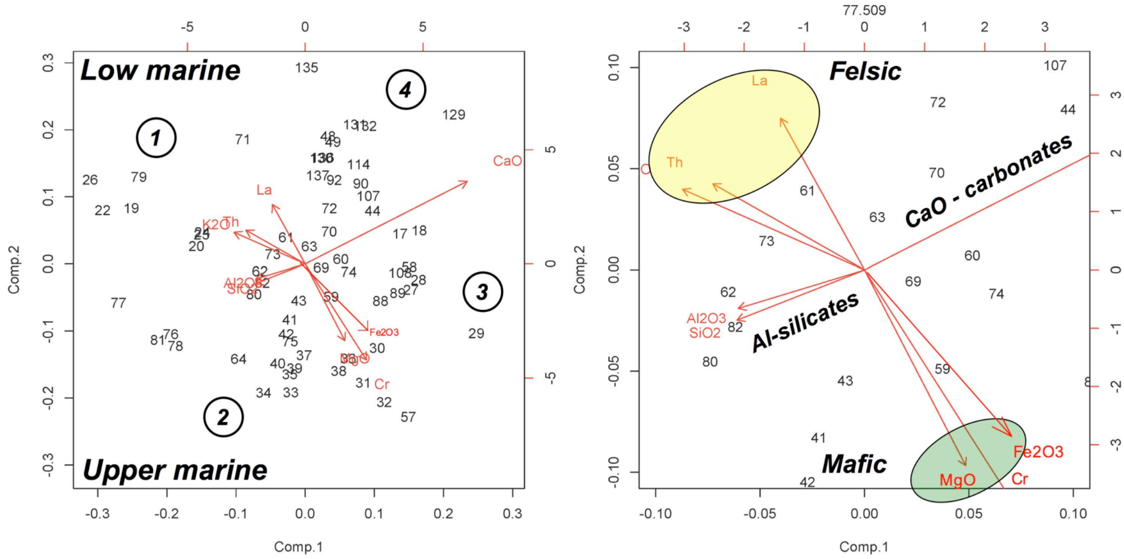



Fig. 6.12 Biplot for deep marine sandstones of Central-Eastern and Southern Rhodopes. Circled numbers identify diagram sectors mentioned in the text. Note the inverse evolution for lower-upper deep marine successions of Southern Rhodopes, from felsic to mafic source areas (right biplot, magnificated).

petrofacies have to be done calling back the two basic concepts described before for biplot interpretation: inverse dependence (180° angle between variables) and independence (orthogonality between two variables). It's clear that, in this case, deep marine sandstone composition is affected by the influence of 4 variables representative of 2 independent processes. In the left part of the diagram there are elements representing the Al-silicates group that result to be inverse-dependent from CaO – carbonates related components. The same happens for the orthogonal axis where mafic source (Ni-Cr side) and felsic source (Th-La side) shows the same inverse dependence.

The 95 % of Southern Rhodopes sandstones are located between the sector 1 and 2, indicating that their composition has been affected by a siliciclastic detritus supply from mafic and felsic source areas. The trend is opposite to the one described for the continental (quartzolithic) sandstones, with older products reflecting a provenance from felsic sources evolving to mafic composition for the younger products. This could be interpreted as a result of the progressive deformation of the basal sequence (continental) that worked as a source area (as suggested by the angular unconformity between the carbonatic platform and the deep marine sequence). This testifies a tectonic event responsible of the emersion of the upper part of the continental succession (felsic) followed by the lower part (mafic). Central-Eastern Rhodopes sandstones are located between sectors 3 and 4, with most of them showing a provenance from multiple, mafic and felsic source areas. Their composition is strongly controlled by CaO content. This could be related to the widespread carbonate cementation and to the high content in sedimentary lithic grains, represented by sparitic and micritic limestones, occurring frequently in Central-Eastern Rhodopes sandstones.

### *6.9.3 Volcanism related sandstones*

Principal component 1 and 2 for Rhodopes volcaniclastic sandstones explain the 75 % of the total variability. Looking at the biplots (fig.6.13) is possible to see that three groups of variables exist and that the angle between theme is of 120°, suggesting a mutual independence of each group from the others. Two of these groups are representative of basic related volcanism (Mg-$Fe_2O_3$ and Ni-Cr-CaO groups) and principally consists of Central-Eastern Rhodopes volcaniclastic samples. The other group of variables (Th-La-$SiO_2$-$Al_2O_3$) is almost exclusively composed of Southern Rhodopes sandstones. Samples from Mesti-Petrotà volcanic area typically shows evidences of contamination by quartz and low-grade metamorphic lithic grains. This justify their position in the proximity with $SiO_2$,$Al_2O_3$ and $K_2O$ variables. Samples from Alexandroupolis volcanic area shows an evolutionary trend from acid to basic type as described by petrographic analysis (fig. 6.13). Central-Eastern Rhodopes volcaniclastic sandstones show a basic (Ni-Cr-CaO group of variables) to intermediate composition (Mg-$Fe_2O_3$-Sc group).

Sandstones from the Krumovgrad area are grouped together (fig.6.13) showing that CaO, Cr and Ni are characteristic of their composition. Petrographically has been described the highest content in plagioclase and volcanic lithic grains with lathwork texture, typical of basalt and basaltic andesites products. In addition, these samples are cemented by carbonate elements, justifying the “weight” of CaO on their composition. Sandstones from Karamfil volcanic area locate in the lower part of the biplot.

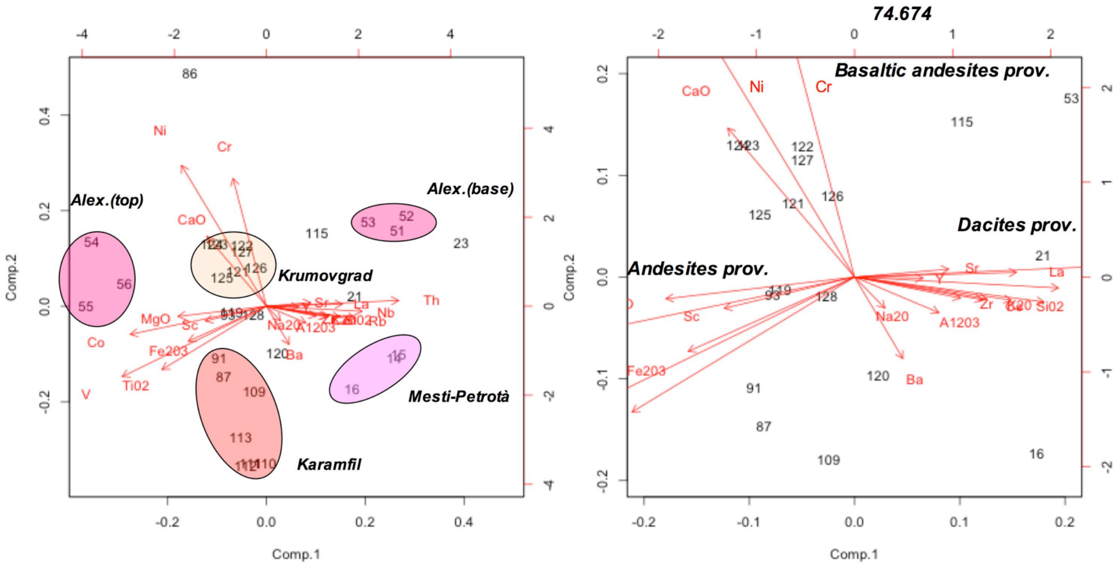



Fig 6.13 Biplot of volcaniclastic sandstones of Central-Eastern and Southern Rhodopes. Note the 120° angle between variables and the clear discrimination in function of the sampling area. On the right side a magnificated version showing different volcanic compositions.

These samples are intermediate in composition as evidenced by the occurrence of volcanic lithic grains with microlithic texture, typical of andesite products. High content in MgO and $Fe_2O_3$ are related to the high content in amphiboles and biotite. Using sub-compositions (Fig. 6.14) relating elements for acidity discrimination, chosen basing on what explained in fig.6.10(d), is possible to figure out diversities among Central-Eastern Rhodopes and Southern Rhodopes volcaniclastic sandstones. It's clear that the occurrence of basic to intermediate products is limited to Central-Eastern Rhodopes arenites. Although the occurrence of andesite volcanism in Southern Rhodopes is widely documented, for analysed sandstones, have been recognized only elements relating to dacite products.

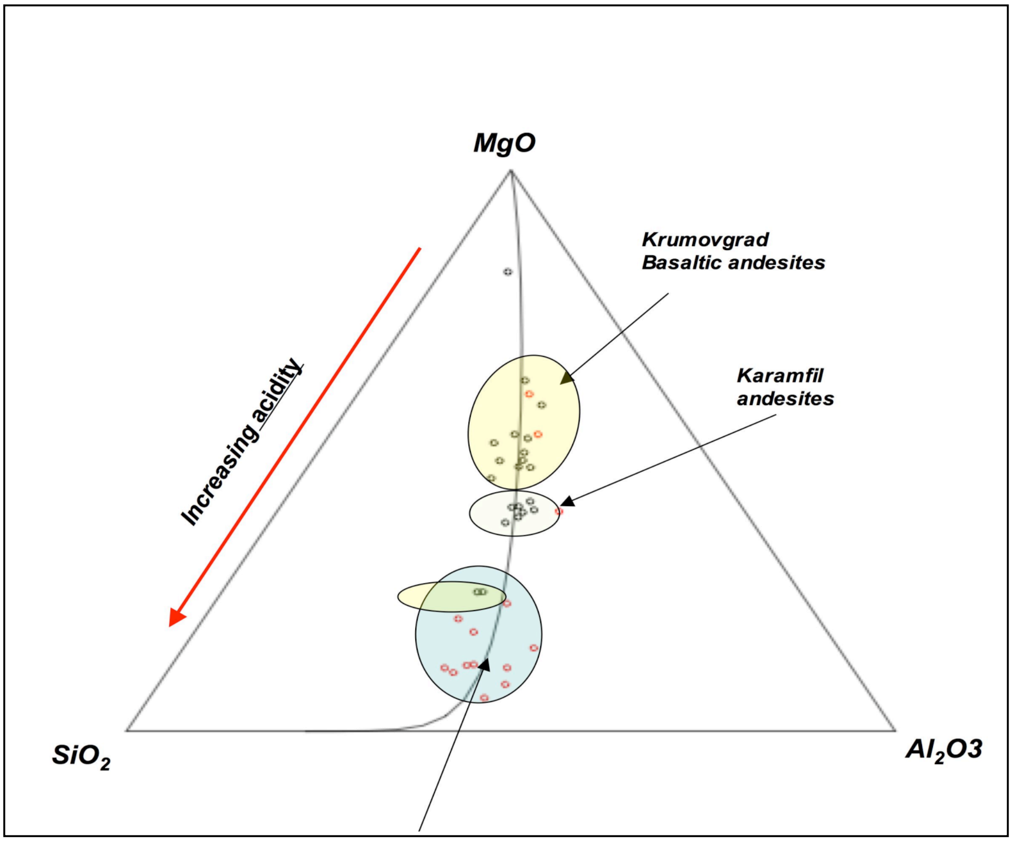



Fig.6.14 Sub-composition chosen from biplot of volcaniclastic sandstones showing the diverse compositions of volcanic sources.

# 7. DISCUSSION

## *7.1 Composition of Rhodopes arenites and controls of system parameters*

Sandstone composition is strongly controlled by rock composition from which they derive. One of the most important factors controlling the source rock composition is definitely the tectonic environment on the source terrain. Krynine (1941 a-c; 1942) assumed the upper crust could be reasonably divided in three layers: an upper layer of dominantly sedimentary rocks; a middle layer of metamorphic rocks; a lower layer of plutonic rocks. He argued that the results of the erosion of this layers, involved in an orogenic process, consists of a succession of sands of quartzose, lithic arenites and arkoses composition respectively reflecting the progressive unroofing of the source terrain.

After the advent of the plate tectonic model has been noted that the distribution of rock types could be explained in terms of tectonic setting and consequently that sandstone composition could be used to deduce ancient tectonic setting as well.

In 1979 Dickinson and Suczeck proposed a model for the correlation between sandstone composition and tectonic. Through the petrographic analysis of 88 sandstones, reported in literature, from different tectonic settings they found a cluster correlation with the tectonic environment of the source terranes.

Three main categories have been recognized: continental block, magmatic arc and recycled orogen. The limits of these categories for the most used ternary diagrams (Qt F L; Qm F Lt) were defined by Dickinson (1983a; 1985).

Hundreds of papers demonstrated the validity of this model in correlating sandstone composition with different tectonic settings even if important exceptions and misclassification occurred (e.g. Molinaroli et al., 1991). Misclassifications or group scattering could be related to the use of different methods (Wolf, 1971; Mack, 1984; Zuffa, 1985; Ingersoll, 1990), sediment recycling (Blatt, 1967), transport through different tectonic settings (Saccani, 1987) and factors affecting sediment during transport, deposition and diagenesis (Suttner, 1974; Jonsson, 1992).

### *7.2 Rhodopes sandstone composition and correlation with tectonic setting*

In this study by plotting the means of each suite on QmFLt ternary diagram, distinct clustering emerged (fig..1). The groupings on the QmFLt diagram defined by (Dickinson and Suczeck, 1979; Dickinson, 1985) do correlate remarkably well with tectonic environment with Rhodopes tectonic environment.

The use of QmFLt framework petrography data has been proved useful to classify Rhodopes arenites by tectonic setting.

Arenites derived from (correggere QR nel diagram in RO) fold thrust belt systems form a quartzolithic (mean value $Qm_{64}F_{15}Lt_{26}$) petrofacies plotting near the Qm-Lt side of the standard triangular diagram (fig..1).

Consistently with the classification scheme, relating arenites composition to the tectonic environments of source terranes (), the quartzolithic petrofacies is low in feldspar grains, lacking in volcanic lithics, and with variable metamorphic lithic grains. Moreover, Qm/Qp and Qp/Ls ratio are variable.

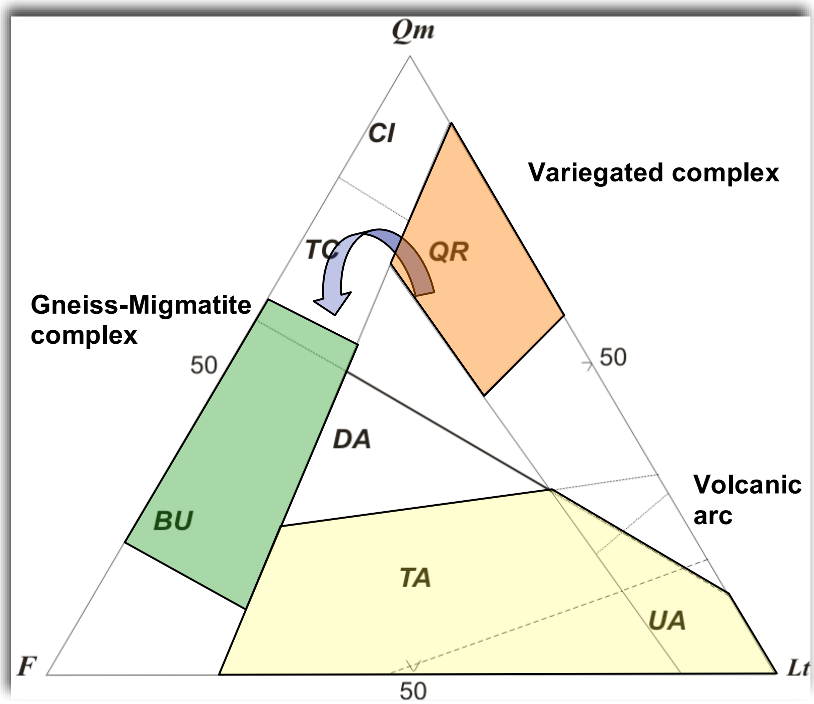



Fig.1 Fig.1 Ternary diagram relating sandstone composition with different tectonic settings. OR, recycled orogen; CI, craton interior; TC, transitional continental; BU, basement uplift; UA. Undissected arc, TA, transitional arc; DA, dissected arc (From Dickinson, 1985)

In addition, lithic fragments of slate and phyllite suggest tectonic provenance from fold-thrust systems of indurated sedimentary and low-grade metamorphic rocks (e.g. Dickinson and Suczeck, 1979; Dickinson, 1985).

Arenites with mean value of $Qm_{46}F_{46}Lt_8$ plot near Qm-F side of the standard triangular diagram (fig..1). The composition of these arkosic arenites (Dickinson, 1985; Valloni et al., 1991) reflects derivation from deeper crustal rocks represent by the Gneiss-Migmatite complex (Mposkos et al., 1998). The Qm/F ratios of the arenites spectrum of this petrofacies are consistent with source areas of rugged topography and arid or semi-arid paleoclimate (e.g. Dickinson, 1985).

The mean composition ($Qm_8F_{37}Lt_{55}$) of these arenites, characterised by framework lithic grains of andesitic composition, suggest an arc derived debris from a tectonic setting of continental arc. High P/K ratios account also for the inferred tectonic setting.

Time-dependent Rhodopes arenitic petrofacies could reflect the evolution of individual provenance terranes through time. No significant contrasts in these petrofacies have been observed as regard diagenetic processes within basin fill.

Stratigraphic field observations and petrofacies variations suggest that the basin evolution recorded major tectonic events. Considerations on the detrital modes of the Rhodopian sandstones suggest a multiple provenance from different tectonic settings. These 3 distinct petrofacies are representative of the geodynamic evolution of the source areas, passing from collision orogenic terranes (unroofing of the metamorphic basement rocks) to a basement uplift, involving the deeper crustal rocks of the Rhodopian Massif to an arc derived sandy detritus.

The use of immobile elements, as Th, Sc, Zr, in tectonic discrimination diagrams (Bathia, 1985; Bathia & Crook, 1986; Mc Lennan; 1993; Floyd et al., 1991; Taylor and Mc Lennan., 1985) evidenced a provenance from source areas developed in continental and oceanic island arcs or, however, from an active continental margin.

### *7.3 Rhodopes sandstone composition and weathering effects*

The degree of alteration attained by sandy detritus depends both on the intensity and the duration of the weathering (Basu, 1985; Johnsson, 1993; Nesbitt and Young, 1982; Le Pera et al., 2001). Intensity of weathering appears to be controlled primarily by climate (precipitation and temperature) and vegetation (particularly the nature and activity of organic acids). The duration of weathering is controlled by many factors, including relief, slope, sediment storage prior to ultimate deposition, and sedimentation rate.

An important basis for interpreting paleoclimate from framework mineralogy is well documented by Suttner & Dutta (1986) even if petrographic analysis of arenites do not provide by themselves an unequivocal basis for interpretation of climate.

The quartzosefeldspathic ($Qm_{46}F_{46}Lt_8$) and volcaniclastic ($Qm_8F_{37}Lt_{55}$) petrofacies are immature, and these compositions could be consistent with temperate climatic conditions. Petrographic analysis of the Rhodopes arenites evidenced the lack of unequivocal indicators of humid paleoclimate (e.g. quartz embayment) during the interval time deposition. In addition, this hypothesis is enhanced also by the occurrence of polimineralic grains and heavy mineral grains characterized by moderately stable species such as Fe-bearing garnet (almandine), amphibole (green hornblende) and epidote. These observations indicate sandy detritus derived directly from the bedrock instead of reworked soils. Under these conditions erosion can be considered in terms of weathering limited denudation regime (e.g. Carson and Kirkby, 1972).

The chemical index of alteration (C.I.A.) for Rhodope arenites has a mean value of 54, suggesting provenances from unweathered bedrock. There is an exception, represented by Oligocene arenites of Southern Rhodopes, which show higher value of the C.I.A. (from 75 to 90). For these samples a K-metasomatism effect has been proposed, following Fedo *et al*. (1995), Fedo *et al.* (1997), Roser *et al*. (2002).

Subsequent to deposition, sediment may be subjected to significant modification in the depositional environment. Mechanical and chemical weathering continue to be of great importance prior to final burial. Davies and Ethridge (1975) suggested that composition reflects characteristics of the depositional environment. By this way, compositional differences could be attributed, in specific case, to depositional environments, mechanical disaggregation and hydrodynamic sorting. This is probably the case of quartzolithic samples, of Avdira section, which show important alteration from kaolinite on K-feldspars. These are part of a continental succession, recognized as part of a braided rivers system. They show characteristics that confirm a provenance from the Variegated Complex, but higher content of quartz. This is not attributable to a lack of feldspars in the source area, but to alteration effects in depositional environments. This idea is supported by the presence of relicts of k-feldspars and plagioclases, as evidenced in chapter 5.

# CONCLUSIONS

The RM massif represent continental fragment generated by the break-up of the super continent Pangea during lower Mesozoic (Dewey et al., 1973; Papanikolau, 1989; Robertson et al., 1991; Burg et al., 1996).

It is generally considered as part of the Alpine orogen, formed due to the convergence processes between african and european plates at the closure of Palaeothethys (Robert and Dickson, 1984; von Braun, 1993).

The collision between African and European plate is responsible of the thickening of the continental crust and of its consequent uplift. The associated sedimentary basins formed starting from Middle Eocene (Lutetian) and developed until the Miocene. These basins developed after an eocenic intense orogenic phase that affected the inner Hellenides in their whole (Jacobsen, 1977).

The stratigraphic data allowed us to reconstruct the general evolution and the spatial and temporal changes of the depositional environment evolving from continental to transitional to deep marine. The evolution of depositional environments reflects a progressive deepening of sedimentary basin.

Data from literature evidenced that the Rhodope Massif is made up of two tectonic unit, showing different cooling/exumation ages. From these data has been possible to identify the Upper Tectonic Unit (Ricou et al., 1998), corresponding to the Variegated Complex (Haydoutov, 2001) as the main source area during the initial stages of deposition (exumation age, 43 Ma). This complex is of oceanic island arc origin (Haydoutov, 2001; 2004) and includes mafic and ultamafic rocks, with small-dismembered bodies of ophiolites. The Variegated complex is irregularly overlain by epimetamorphic rocks of the Circum-Rhodope Belt, consisting of low-medium grade metamorohic rocks, as phyllite and mica-schists.

The Lower Tectonic Unit (Ricou et al., 1998), or Gneiss-Migmatite Complex (Haydoutov, 2001) has an exumation age of 38 Ma, and worked as source area during the whole Oligocene.

The petrographic analysis define three petrofacies evolving, upward in the stratigraphic section, from quartzolithic to quartzosefeldspathic to volcaniclastic composition of the framework detrital modes.

The quartzolithic petrofacies includes lithic fragments reflecting a provenance from the Variegated Complex and the Makri Unit, as testified by extremenly high content of phyllite and mica-schist lithic grains. Central-Eastern Rhodopes quartzolithic sandstones includes ophiolite lithic fragments according to the presence of ophiolite bodies, and oceanic island arc origin of the Variegated Complex.

The quartzosefeldspathic petrofacies reflects the evolution of the accretionary processes, and the consequent uplift of deeper level of continental crust, here represented by the Gneiss-Migmatite Complex. This theory is supported by the occurrence of garnet-rich amphibolites and epidote-schist, that are characteristic rocks of the Gneiss-Migmatite Complex.

The volcaniclastic petrofacies testify the onset of two different volcanic belt developed starting from Priabonian, in Central-Eastern Rhodopes, and from the lower Oligocene in Southern Rhodopes. The prevalence of neo-volcanic lithic grains showing microlithic and lathwork textures in Central – Eastern Rhodopes suggests a dominant volcanic activity with basic-intermediate compositions. The occurrence of brown-orange volcanic glasses supports the occurrence of submarine eruptions in the area.

Volcaniclastic sandstones of Southern Rhodopes are characteristic of a provenance from more acid products, as testified by neo-volcanic lithic grains with felsitic, both, granular and seriate textures, and black volcanic glasses. Other "acid indicators" are represented by the occurrence of sanidine and high $SiO_2$ content of welded glasses.

On the base of petrofacies clustering geochemical data have been evaluated taking in account their compositional hierarchy. Geochemical data have been treated through multivariate statistical techniques which amplified the provenance signals of each petrofacies.

The use of variation array and biplot for quartzolithic petrofacies evidenced that there are element associations which allows to obtain a more detailed discrimination between Southern and Central-Eastern Rhodopes sandstones.

On the base of their compositional features has been noted that, despite of same petrographic composition, sandstone of different areas substantially differs in function of siliciclastic and carbonates content. Specifically, has been documented that Southern Rhodope samples are supplied by siliciclastic detritus, and reflect a evolutionary trend from mafic to felsic sources. Central-Eastern Rhodope sandstones are extremely rich in carbonatic detritus and calcite cements, reflecting the supply from Cretaceous limestone reefs.

Stratigraphic, petrografic and geochemical data evaluations allowed to produce an unroofing model of the Rhodope orogen. According to Dickinson (1985), the detrital modes of the Rhodopian sandstones suggest a multiple provenance from different tectonic settings. These 3 distinct petrofacies are representative of the geodynamic evolution of the source areas, passing from collision orogenic terranes (unroofing of the metamorphic basement rocks) to a basement uplift, involving the deeper crustal rocks of the Rhodopian Massif (gneiss, amphibolite and plutonic rocks) to an arc derived sandy detritus.

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APPENDIX

1) PETROLOGY

PETROGRAPHIC CLASSES:

**Lithic grains**

| | Qm-F-Lt | Qt-F-L | Qm-K-P | Qp-Lvm-Lsm | Lm-Lv-Ls | Rg-Rv-Rm |
|---|---|---|---|---|---|---|
| Volcanic lithic with microlitic texture | Lt | L | | Lvm | Lv | Rv |
| Volcanic lithic with lathwork texture | Lt | L | | Lvm | Lv | Rv |
| Volcanic lithic with vitric texture | Lt | L | | Lvm | Lv | Rv |
| Volcanic lithic with felsitic granular texture | Lt | L | | Lvm | Lv | Rv |
| Volcanic lithic with felsitic seriate texture | Lt | L | | Lvm | Lv | Rv |
| Serpentinite schist | Lt | L | | Lvm | Lm | Rm |
| Phyllite lithic fragment | Lt | L | | Lsm | Lm | Rm |
| Fine grained micaschist lithic fragment | Lt | L | | Lsm | Lm | Rm |
| Impure chert | Lt | Qt | | Qp | Ls | |
| Siltstone | Lt | L | | Lsm | Ls | |
| Shale lithic fragment | Lt | L | | Lsm | Ls | |
| Slate lithic fragment | Lt | L | | Lsm | Lm | Rm |
| Extrabasinal carbonate grains (CE) | | | | | | |
| Micritic limestone | | | | Lsm | Ls | |
| Sparitic limestone | | | | Lsm | Ls | |
| Biomicritic/biosparitic limestone | | | | Lsm | Ls | |
| Foliated limestone | Lt | L | | Lsm | Lm | |

**Quartz (Qt=Qm+Qp)**

| | Qm-F-Lt | Qt-F-L | Qm-K-P | Qp-Lvm-Lsm | Lm-Lv-Ls | Rg-Rv-Rm |
|---|---|---|---|---|---|---|
| Quartz (single crystal) | Qm | Qt | Qm | | | |
| Polycrystalline quartz with tectonic fabric | Lt | Qt | | Qp | | |
| Polycrystalline quartz without tectonic fabric | Lt | Qt | | Qp | | |
| Quartz in metamorphic r.f. | Qm | Qt | Qm | | | Rm |
| Quartz in plutonic r.f. | Qm | Qt | Qm | | | Rg |
| Quartz in plutonic or gneissic r.f. | Qm | Qt | Qm | | | Rg |
| Quartz in sandstones | Qm | Qt | Qm | | | |
| Calcite replacement on quartz | Qm | Qt | Qm | | | |
| Epidote replacement on quartz | | | | | | |

**Feldspars (F=K+P)**

| | Qm-F-Lt | Qt-F-L | Qm-K-P | Qp-Lvm-Lsm | Lm-Lv-Ls | Rg-Rv-Rm |
|---|---|---|---|---|---|---|
| K-feldspar (single crystal) | F | F | K | | | |
| K-feldspar in metamorphic r.f. | F | F | K | | | Rm |
| K-feldspar in plutonic r.f | F | F | K | | | Rg |
| K-feldspar in plutonic or gneissic r.f. | F | F | K | | | Rg |
| K-feldspar in sedimentary rock fragment | F | F | K | | | |
| Calcite replacement on K-feldspar | F | F | K | | | |
| Calcite replacement on undetermined feldspar | | | | | | |
| Plagioclase (single crystal) | F | F | P | | | |
| Plagioclase in metamorphic r.f. | F | F | P | | | Rm |
| Plagioclase in plutonic r.f. | F | F | P | | | Rg |
| Plagioclase in plutonic or gneissic r.f. | F | F | P | | | Rg |
| Calcite replacement on plagioclase | F | F | P | | | |
| Epidote replacement on plagioclase | | | | | | |

**Phyllosilicate and dense minerals**

| | Qm-F-Lt | Qt-F-L | Qm-K-P | Qp-Lvm-Lsm | Lm-Lv-Ls | Rg-Rv-Rm |
|---|---|---|---|---|---|---|
| Phyllosilacate (single crystal) | | | | | | |
| Phyllosilacate in metamorphic r.f. | | | | | | Rm |
| Phyllosilacate in plutonic r.f. | | | | | | Rg |
| Phyllosilacate in plutonic or gneissic r.f. | | | | | | Rg |
| Dense mineral (single crystal) | | | | | | |
| Dense mineral in metamorphic r.f. | | | | | | Rm |
| Dense mineral in plutonic r.f. | | | | | | Rg |

Table (). Categories used for sandstones point-counts of framework grains and assigned grains in recalculated plots. Criteria for temporal and textural subdivision of volcanic grains are those of Dickinson (1970), Zuffa (1987), and Critelli and Ingersoll (1995). Rock fragment recalculations are those of Critelli & Le Pera (1994).

DETRITAL MODES - SOUTHERN RHODOPES:

| | SC-746 | SC-747 | SC-748 | SC-749 | SC-750 | SC- 751 | SC-752 | SC-753 | SC-754 | SC-755 | SC-756 | SC-757 | SC-758 | SC-761 | SC-762 | SC-763 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| NCE | | | | | | | | | | | | | | | | |
| Quartz (single crystal) | 62 | 46 | 68 | 96 | 95 | 98 | 74 | 78 | 135 | 70 | 81 | 143 | 115 | 29 | 76 | 81 |
| Polycrystalline quartz with tectonic fabric | 32 | 10 | 12 | 23 | 11 | 21 | 52 | 5 | 27 | 16 | 32 | 14 | 28 | 7 | 7 | 2 |
| Polycrystalline quartz without tectonic fabric | – | 2 | 2 | – | – | – | 56 | – | – | – | – | – | – | 5 | 3 | 1 |
| Quartz in volcanic r.f. | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Quartz in metamorphic r.f. | 60 | 70 | 79 | 58 | 71 | 79 | 97 | 73 | 100 | 140 | 88 | 71 | 55 | 64 | 6 | 8 |
| Quartz in plutonic r.f. | 12 | 11 | 14 | 8 | 21 | 3 | 29 | 6 | 16 | 1 | 4 | 2 | 6 | – | 4 | 1 |
| Quartz in plutonic or gneissic r.f. | 9 | 9 | 42 | 25 | 42 | 26 | 8 | 35 | 17 | 27 | 29 | 17 | 24 | 2 | 2 | – |
| Quartz in sandstones | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Calcite replacement on quartz | – | – | – | – | 1 | 2 | – | – | – | – | – | – | – | – | 3 | 5 |
| Epidote replacement on quartz | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| K-feldspar (single crystal) | 13 | 9 | 11 | 11 | 15 | 22 | 17 | 8 | 21 | 6 | 22 | 8 | 6 | 48 | 42 | 44 |
| K-feldspar in volcanic r.f. | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| K-feldspar in metamorphic r.f. | 4 | 6 | – | 2 | 5 | – | 5 | 4 | – | 3 | 1 | – | – | 10 | 7 | – |
| K-feldspar in plutonic r.f | 1 | 7 | 1 | – | 1 | – | 6 | – | 4 | – | – | – | – | – | 4 | 2 |
| K-feldspar in plutonic or gneissic r.f. | 4 | 12 | 39 | 32 | 27 | 25 | 9 | 28 | 18 | 32 | 26 | 5 | 14 | – | 2 | – |
| Calcite replacement on K-feldspar | – | – | 4 | – | 4 | – | – | – | – | – | – | – | – | – | 6 | 7 |
| Calcite replacement on undetermined K-feldspar | – | – | – | – | – | – | – | – | – | – | – | – | – | – | 6 | – |
| Plagioclase (single crystal) | 6 | 1 | – | – | – | – | – | – | 2 | – | – | – | – | 30 | 84 | 84 |
| Plagioclase in metamorphic r.f. | – | – | – | – | – | – | 1 | – | – | – | – | – | – | 10 | 7 | 7 |
| Plagioclase in plutonic r.f. | – | – | – | – | – | – | – | – | – | – | – | – | – | – | 3 | 3 |
| Plagioclase in plutonic or gneissic r.f. | 5 | – | 1 | – | – | – | 1 | – | – | 1 | 1 | – | – | 1 | 6 | 6 |
| Calcite replacement on plagioclase | 3 | – | – | – | – | – | – | – | – | – | – | – | – | – | 13 | 13 |
| Calcite replacement on undeterminate feldspar | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Epidote replacement on plagioclase | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Phyllosilacate (single crystal) | – | – | – | – | – | – | – | – | – | – | – | – | – | 12 | – | 8 |
| Phyllosilacate in metamorphic r.f. | – | 1 | 4 | 4 | 3 | 5 | 4 | 13 | – | 16 | 2 | 8 | 14 | 5 | 8 | – |
| Phyllosilacate in plutonic r.f. | 1 | – | – | – | – | – | – | – | – | – | – | – | – | – | – | 3 |
| Phyllosilacate in plutonic or gneissic r.f. | – | – | – | – | – | – | – | – | – | – | – | 1 | – | – | 3 | – |
| Phyllosilacate in volcanic r.f. | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Chlorite | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Lithic fragments | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Volcanic lithic with microlitic texture | – | – | – | – | – | – | – | – | – | – | – | – | – | 2 | – | – |
| Volcanic lithic with lathwork texture | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Volcanic lithic with vitric texture | – | – | – | – | – | – | 1 | – | – | – | – | – | – | 112 | – | – |
| Volcanic lithic with felsitic granular texture | – | – | – | – | – | – | 7 | – | – | – | – | – | – | – | – | – |
| Volcanic lithic with felsitic seriate texture | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Serpentinite schist | – | – | – | – | – | – | – | – | – | – | – | – | – | 13 | – | – |

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Slate lithic fragment | – | – | – | – | – | – | – | – | – | – | 1 | – | 1 | – | – | – |
| Phyllite lithic fragment | 24 | 19 | 34 | 31 | 34 | 45 | 62 | 11 | 11 | 16 | 29 | 17 | 22 | 15 | 8 | 11 |
| Fine grained micaschist lithic fragment | – | – | – | – | – | 1 | – | – | – | – | – | – | – | – | 5 | 4 |
| Chlorite-schist lithic fragment | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Amphibolite lithic fragment | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Epidote-schist litic fragment | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Shale lithic fragment | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Impure chert | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Siltstone | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Micaschist | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Neo Volcanic | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Quartz in neovolcanic r.f. | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Plagioclase single euhedral | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| K-feldspar single euhedral | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Plagioclase in neovolcanic | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| K-feldspar in neovolcanic | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Phyllosilicate in neovolcanic r.f. | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Volcanic lithic with microlitic texture | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Volcanic lithic with lathwork texture | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Volcanic lithic with vitric texture | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Volcanic lithic with felsitic granular texture | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Volcanic lithic with felsitic seriate texture | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Brown Glasses | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Colourless | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Biotite in neovolcanic | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Pumice and shard fragments | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Vitric pumice | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Dense neovolcanic | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Dense minerals | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Dense mineral (single crystal) | 1 | 1 | – | – | – | 1 | 3 | – | 1 | – | – | – | 1 | – | – | – |
| Apathite (single crystal) | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Tourmaline (single crystal) | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Horneblende (single crystal) | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Piroxene (single crystal) | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Rutile (single crystal) | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Neovolcanic horneblende (single crystal) | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Titanite (single crystal) | 1 | 3 | – | 2 | – | – | – | – | – | – | – | – | 1 | – | – | – |
| Epidote (single crystal) | – | – | – | – | – | – | – | 1 | – | – | – | – | 1 | – | – | – |
| Zircon (single crystal) | – | – | – | – | – | – | – | – | 1 | – | – | 1 | – | – | – | – |
| Granat (single crystal) | – | 1 | – | – | 1 | 2 | – | – | – | 3 | – | 1 | – | – | – | – |
| Neovolcanic piroxene (singolo cristallo) | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Epidote in metamorphic r.f. | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Horneblende in plutonic r.f. | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Horneblende in neovulcanic r.f. | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Titanite in plutonic r.f. | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Epidote in plutonic r.f. | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Zircon in plutonic r.f. | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Granat in metamorphic r.f. | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Amphibole in metamorphic r.f. | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Piroxene in neovolcanic r.f. | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Epidote in neovolcanic r.f. | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Dense mineral in neovolcanic r.f. | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Opaque minerals | – | – | – | – | – | – | – | 1 | – | – | – | – | – | – | – | – |
| Amphibole (single crystal) | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Calcite replacement on epidote | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| CE | | | | | | | | | | | | | | | | |
| Micritic limestone | – | – | – | – | 3 | – | – | – | – | – | – | – | – | – | 65 | 58 |
| Sparitic limestone | – | – | – | – | – | – | – | – | – | – | – | – | – | – | 13 | 4 |
| Biosparitic limestone | – | – | – | – | – | – | – | – | – | – | – | – | – | – | 6 | 3 |
| Biomicritic limestone | – | – | – | – | – | – | – | – | – | – | – | – | – | – | 1 | – |
| Fossil (single skeleton) | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Single spar (calcite) | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Foliated limestone | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Silty-arenitic limestone | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| CI | | | | | | | | | | | | | | | | |
| Bioclast | – | – | – | 1 | – | – | – | – | – | – | – | – | – | – | 36 | 43 |
| Intraclast | – | – | – | – | – | – | – | – | – | – | – | – | – | – | 3 | 1 |
| NCI | | | | | | | | | | | | | | | | |
| Glauconite | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Rip-up clasts | – | – | – | 34 | 29 | 6 | – | – | – | – | – | – | 2 | – | – | – |
| Oxid-fe | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Mx | | | | | | | | | | | | | | | | |
| Siliciclastic matrix | – | – | – | – | – | – | – | – | – | – | – | – | – | – | 9 | 5 |
| Carbonate matrix | – | – | – | – | – | – | – | – | – | – | – | – | – | – | 13 | 8 |
| Volcaniclastic matrix | – | – | – | – | – | – | – | – | – | – | – | – | – | 137 | – | – |
| Pseudo-matrix | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Cm | | | | | | | | | | | | | | | | |
| Carbonate cement (pore-filling) | – | – | – | – | – | – | – | – | – | – | – | – | – | – | 74 | 82 |
| Carbonate cements (patchy calcite) | – | 2 | – | 2 | – | – | – | – | – | – | – | – | – | – | – | – |
| Siliceous cement | – | – | 35 | 16 | 49 | 29 | – | 80 | 55 | 61 | 39 | 105 | 125 | – | – | – |
| Phyllosilicate cement | 73 | 72 | 22 | 15 | 33 | 26 | 20 | 44 | 78 | 55 | 125 | 136 | 78 | – | – | – |
| Oxid-fe cement | 2 | – | – | – | 1 | 2 | – | 10 | – | 8 | 6 | – | – | – | – | – |
| Siliceous cement | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Kaolinite cement | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Quartz overgrowth | 3 | 1 | 1 | – | 1 | – | – | – | 2 | – | – | – | – | – | – | – |
| Calcite replacement on undetermined grain | 182 | 163 | 120 | 58 | 22 | 79 | – | – | – | – | – | – | – | – | 23 | – |
| Clay and clay grain coats | 6 | 6 | – | 2 | 10 | – | 13 | – | 4 | – | 6 | – | 1 | – | – | – |
| Undetermined grain | – | – | – | – | – | – | – | – | 0 | – | – | – | – | – | – | – |
| Alterite | – | – | – | 17 | – | 27 | 16 | – | 13 | – | 3 | 6 | 26 | – | – | – |
| Undeterminate | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| N= | 311 | 282 | 260 | 214 | 217 | 569 | 137 | 188 | 185 | 192 | 238 | 280 | 286 | 502 | 398 | 352 |

Tab.1
NCE=Non-carbonate extrabasinal grains; CE=Extrabasinal carbonate grains; CI= Carbonate intrabasinal grains
Paleo-V=palaeo volcanic grains; Neo-V=neovolcanic grains; NCI=Non-carbonate intrabasinal grains;
Ce=cements; Mx=matrix

| | SC-764 | SC-765 | SC-766 | SC-767 | SC-769 | SC-770 | SC-771 | SC-772 | SC-773 | SC-774 | SC-775 | SC-776 | SC-777 | SC-778 | SC-779 | SC-780 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| NCE | | | | | | | | | | | | | | | | |
| Quartz (single crystal) | 180 | 31 | 14 | 137 | 34 | 42 | 88 | 121 | 153 | 133 | 129 | 59 | 66 | 89 | 110 | 59 |
| Polycrystalline quartz with tectonic fabric | | 1 | 2 | – | – | 1 | – | 4 | 8 | – | – | 2 | 2 | 2 | 16 | 8 |
| Polycrystalline quartz without tectonic fabric | 3 | 1 | – | 4 | 2 | 2 | 14 | 4 | 7 | 5 | 7 | 5 | – | 3 | 4 | 5 |
| Quartz in volcanic r.f. | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Quartz in metamorphic r.f. | 20 | 33 | 21 | 45 | 25 | 31 | 38 | 41 | 45 | 30 | 30 | 80 | 87 | 34 | 122 | 142 |
| Quartz in plutonic r.f. | 3 | 1 | – | 10 | 7 | 3 | 7 | – | – | – | – | 10 | 6 | 11 | – | 5 |
| Quartz in plutonic or gneissic r.f. | 1 | – | – | 3 | 1 | 3 | – | – | – | – | – | 2 | 3 | 6 | – | 6 |
| Quartz in sandstones | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Calcite replacement on quartz | – | – | – | – | – | – | – | 3 | 16 | 3 | 1 | – | – | – | – | – |
| Epidote replacement on quartz | – | – | – | – | – | – | – | – | – | – | – | 4 | – | – | – | – |
| K-feldspar (single crystal) | 116 | 8 | – | 130 | 56 | 12 | 104 | 41 | 9 | 27 | 36 | 61 | 59 | 60 | 17 | 52 |
| K-feldspar in volcanic r.f. | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| K-feldspar in metamorphic r.f. | 1 | 1 | – | – | 1 | 2 | 3 | 1 | 4 | – | – | 9 | 17 | 3 | 3 | 21 |
| K-feldspar in plutonic r.f | 8 | – | – | 8 | 1 | 1 | 4 | – | – | – | – | 3 | 3 | 10 | – | 2 |
| K-feldspar in plutonic or gneissic r.f. | – | – | – | 2 | – | – | – | – | – | – | – | – | 2 | – | – | 1 |
| Calcite replacement on K-feldspar | – | – | – | – | – | – | – | – | – | 1 | – | – | – | – | – | – |
| Calcite replacement on undetermined K-feldspar | – | – | – | – | – | – | – | 4 | – | – | 1 | – | – | – | – | – |
| Plagioclase (single crystal) | 66 | 62 | – | 26 | 91 | 86 | 53 | 57 | 60 | 51 | 132 | 90 | 55 | 72 | 96 | 52 |
| Plagioclase in metamorphic r.f. | 2 | 15 | – | 10 | 13 | 8 | 8 | – | – | 1 | 5 | 43 | 46 | 11 | 33 | 33 |
| Plagioclase in plutonic r.f. | 2 | 2 | – | 2 | 3 | 5 | 2 | – | – | – | – | 9 | 12 | 12 | 1 | 2 |
| Plagioclase in plutonic or gneissic r.f. | | 1 | – | – | – | – | – | – | – | – | – | 5 | 2 | 2 | 4 | 1 |
| Calcite replacement on plagioclase | 15 | – | – | – | – | – | – | 16 | 21 | 19 | 21 | – | – | – | – | – |
| Calcite replacement on undeterminate feldspar | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Epidote replacement on plagioclase | – | – | – | – | – | – | – | – | – | – | – | 6 | – | – | – | – |
| Phyllosilacate (single crystal) | 9 | 29 | – | 1 | 39 | 33 | 3 | 26 | 13 | 25 | 27 | – | 14 | 8 | 2 | 16 |
| Phyllosilacate in metamorphic r.f. | – | 7 | 11 | 3 | 10 | 18 | 2 | – | 5 | – | – | – | 5 | 1 | 1 | 2 |
| Phyllosilacate in plutonic r.f. | | – | – | – | 1 | 2 | – | – | – | – | – | – | – | – | – | – |
| Phyllosilacate in plutonic or gneissic r.f. | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Phyllosilacate in volcanic r.f. | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Chlorite | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Lithic fragments | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Volcanic lithic with microlitic texture | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Volcanic lithic with lathwork texture | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Volcanic lithic with vitric texture | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Volcanic lithic with felsitic granular texture | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Volcanic lithic with felsitic seriate texture | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Serpentinite schist | – | – | – | 1 | – | – | 2 | – | – | – | – | – | – | – | – | – |
| Slate lithic fragment | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | 1 |
| Phyllite lithic fragment | – | 17 | 2 | – | 7 | – | – | 15 | 6 | 5 | – | | 2 | 6 | 4 | 8 |
| Fine grained micaschist lithic fragment | – | 39 | – | – | 9 | 23 | 1 | 7 | 5 | 19 | 3 | 18 | 11 | 23 | 7 | 11 |
| Chlorite-schist lithic fragment | – | – | – | – | – | – | – | – | – | – | 7 | – | – | 5 | 12 | – |

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Amphibolite lithic fragment | – | – | 4 | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Epidote-schist litic fragment | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Shale lithic fragment | – | – | – | – | – | – | – | 4 | – | – | – | – | – | – | – | – |
| Impure chert | 11 | – | – | – | – | – | – | 5 | 1 | 3 | – | – | – | – | – | – |
| Siltstone | – | – | – | – | – | – | – | – | – | – | – | – | 1 | – | – | – |
| Micaschist | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Neo Volcanic | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Quartz in neovolcanic r.f. | – | – | 6 | – | – | 2 | – | – | – | – | – | – | – | – | – | – |
| Plagioclase single euhedral | 1 | 1 | 23 | – | – | 4 | – | – | – | – | – | – | – | – | – | – |
| K-feldspar single euhedral | – | – | 5 | – | – | 1 | – | – | – | – | – | – | – | – | – | – |
| Plagioclase in neovolcanic | 1 | – | 11 | – | – | – | – | – | – | – | – | – | – | – | – | – |
| K-feldspar in neovolcanic | – | – | 14 | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Phyllosilicate in neovolcanic r.f. | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Volcanic lithic with microlitic texture | 5 | 14 | 24 | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Volcanic lithic with lathwork texture | – | – | – | – | 1 | – | 3 | – | – | – | – | – | – | – | – | – |
| Volcanic lithic with vitric texture | 40 | 87 | 157 | 56 | 67 | 110 | 43 | – | – | – | – | – | – | – | – | – |
| Volcanic lithic with felsitic granular texture | – | – | 19 | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Volcanic lithic with felsitic seriate texture | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Brown Glasses | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Colourless | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Biotite in neovolcanic | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Pumice and shard fragments | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Vitric pumice | – | 32 | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Dense neovolcanic | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Dense minerals | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Dense mineral (single crystal) | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Apathite (single crystal) | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Tourmaline (single crystal) | – | 3 | – | – | – | – | – | – | – | – | 2 | – | – | – | – | – |
| Horneblende (single crystal) | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Piroxene (single crystal) | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Rutile (single crystal) | – | 4 | – | – | – | – | – | – | – | – | – | – | – | – | – | 4 |
| Neovolcanic horneblende (single crystal) | – | – | 3 | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Titanite (single crystal) | – | – | – | – | – | – | – | – | – | – | – | 5 | 3 | – | – | 1 |
| Epidote (single crystal) | – | – | – | – | – | – | – | – | 2 | – | 6 | 63 | 33 | 5 | – | 16 |
| Zircon (single crystal) | – | – | – | – | 1 | – | – | 2 | – | – | – | – | – | – | – | – |
| Granat (single crystal) | – | – | – | – | – | – | – | – | 1 | – | – | 3 | – | – | – | 6 |
| Neovolcanic piroxene (singolo cristallo) | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Epidote in metamorphic r.f. | – | – | 1 | – | – | – | – | – | – | – | – | 19 | 27 | – | – | 12 |
| Horneblende in plutonic r.f. | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Horneblende in neovulcanic r.f. | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Titanite in plutonic r.f. | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Epidote in plutonic r.f. | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Zircon in plutonic r.f. | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Granat in metamorphic r.f. | – | – | 1 | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Amphibole in metamorphic r.f. | – | – | 1 | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Piroxene in neovolcanic r.f. | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Epidote in neovolcanic r.f. | – | – | 1 | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Dense mineral in neovolcanic r.f. | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Opaque minerals | – | – | – | – | – | – | – | 1 | – | 2 | – | – | – | – | – | – |
| Amphibole (single crystal) | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Calcite replacement on epidote | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| CE | | | | | | | | | | | | | | | | |
| Micritic limestone | – | – | – | – | – | – | – | 16 | 13 | – | 21 | – | – | – | – | – |
| Sparitic limestone | – | – | – | – | – | – | – | – | – | – | 5 | – | – | – | – | – |
| Biosparitic limestone | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Biomicritic limestone | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Fossil (single skeleton) | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Single spar (calcite) | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Foliated limestone | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Silty-arenitic limestone | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| CI | | | | | | | | | | | | | | | | |
| Bioclast | – | – | – | – | – | – | – | – | 3 | – | – | – | – | – | – | – |
| Intraclast | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| NCI | | | | | | | | | | | | | | | | |
| Glauconite | – | – | 1 | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Rip-up clasts | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Oxid-fe | – | – | – | – | – | – | – | – | 4 | – | 1 | – | – | – | – | – |
| Mx | | | | | | | | | | | | | | | | |
| Siliciclastic matrix | 50 | 19 | – | 7 | 4 | – | 118 | 32 | 37 | 23 | 43 | 23 | 61 | 57 | 85 | 29 |
| Carbonate matrix | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Volcaniclastic matrix | – | 148 | 74 | – | 133 | 115 | 3 | – | – | – | – | – | – | – | – | – |
| Pseudo-matrix | – | – | – | – | 1 | – | – | 1 | – | 1 | – | – | 3 | 15 | 7 | 6 |
| Cm | | | | | | | | | | | | | | | | |
| Carbonate cement (pore-filling) | – | – | – | – | – | – | – | 26 | 6 | 46 | – | – | – | – | – | – |
| Carbonate cements (patchy calcite) | – | – | – | – | – | – | – | 61 | 46 | 98 | – | – | – | – | – | – |
| Siliceous cement | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Phyllosilicate cement | 1 | – | – | – | – | – | – | – | – | – | – | – | – | – | 1 | – |
| Oxid-fe cement | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Siliceous cement | – | – | 1 | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Kaolinite cement | – | – | – | 80 | – | – | 22 | – | – | 1 | 1 | 3 | 6 | – | – | 4 |
| Quartz overgrowth | – | – | – | – | – | – | – | – | – | – | – | – | – | – | 1 | – |
| Calcite replacement on undetermined grain | – | – | – | – | – | – | – | 16 | 27 | 9 | 28 | – | – | – | – | – |
| Clay and clay grain coats | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Undetermined grain | – | – | – | – | 1 | – | 1 | 3 | 2 | 4 | – | – | – | – | – | – |
| Alterite | – | 12 | 5 | – | 4 | 10 | 4 | – | – | – | 6 | – | – | – | – | – |
| Undeterminate | | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| N= | 211 | 568 | 401 | 525 | 512 | 514 | 523 | 507 | 494 | 506 | 512 | 522 | 526 | 435 | 526 | 505 |

| | SC-781 | SC-782 | SC-783 | SC-785 | SC-786 | SC-787 | SC-788 | SC-789 | SC-790 | SC-791 | SC-793 | SC-794 | SC-795 | SC-796 | SC-797 | SC-799 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| NCE | | | | | | | | | | | | | | | | |
| Quartz (single crystal) | 134 | 57 | 107 | 126 | 109 | 114 | 104 | 71 | 120 | 84 | 136 | 146 | 161 | 8 | 26 | 1 |
| Polycrystalline quartz with tectonic fabric | 9 | 3 | 2 | 5 | 1 | 4 | 6 | 2 | 8 | 10 | 2 | 17 | 37 | 5 | 1 | 3 |

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Polycrystalline quartz without tectonic fabric | 14 | 3 | 3 | 7 | 2 | 4 | 9 | 2 | 21 | 27 | 1 | 9 | 4 | 12 | 1 | 1 |
| Quartz in volcanic r.f. | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Quartz in metamorphic r.f. | 133 | 138 | 73 | 47 | 83 | 63 | 114 | 51 | 116 | 131 | 34 | 101 | 33 | 7 | – | – |
| Quartz in plutonic r.f. | – | 16 | 8 | 4 | | 2 | 21 | 27 | 6 | 12 | 14 | 1 | 7 | – | – | – |
| Quartz in plutonic or gneissic r.f. | 1 | 7 | 5 | 1 | 2 | 2 | 9 | – | 1 | 2 | 6 | 1 | 21 | – | – | – |
| Quartz in sandstones | – | – | – | – | – | – | – | – | – | – | – | – | 0 | – | – | – |
| Calcite replacement on quartz | – | – | 6 | – | – | – | – | – | 1 | 1 | 3 | 17 | 4 | – | – | – |
| Epidote replacement on quartz | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| K-feldspar (single crystal) | 21 | 63 | 46 | 25 | 31 | 36 | 19 | 35 | 17 | 14 | 42 | 34 | 21 | – | – | – |
| K-feldspar in volcanic r.f. | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| K-feldspar in metamorphic r.f. | 7 | 20 | 13 | 3 | 7 | 10 | 21 | 3 | 2 | 1 | 14 | 5 | 1 | 1 | – | – |
| K-feldspar in plutonic r.f | – | 15 | – | 1 | 5 | 2 | 12 | 19 | – | 1 | 2 | 4 | 2 | – | – | – |
| K-feldspar in plutonic or gneissic r.f. | – | 2 | – | – | 1 | – | 2 | 1 | – | – | 4 | 1 | 16 | – | – | – |
| Calcite replacement on K-feldspar | 1 | – | 7 | – | – | – | – | – | 5 | – | 6 | 10 | 2 | – | – | – |
| Calcite replacement on undetermined K-feldspar | 1 | – | – | – | 3 | – | 4 | – | 1 | – | – | – | – | – | – | – |
| Plagioclase (single crystal) | 61 | 38 | 99 | 80 | 67 | 71 | 45 | 36 | 8 | 25 | 102 | 34 | 29 | – | – | – |
| Plagioclase in metamorphic r.f. | 28 | 30 | 18 | 12 | 18 | 38 | 31 | 7 | 6 | 16 | 12 | 5 | – | – | – | – |
| Plagioclase in plutonic r.f. | – | 7 | 5 | 4 | 2 | 6 | 7 | 18 | 1 | 2 | 6 | 2 | 2 | – | – | – |
| Plagioclase in plutonic or gneissic r.f. | – | 2 | 3 | – | 1 | 2 | 6 | – | – | – | – | – | 8 | – | – | – |
| Calcite replacement on plagioclase | 3 | – | – | – | 1 | – | – | 1 | 8 | – | 10 | 17 | – | – | – | – |
| Calcite replacement on undeterminate feldspar | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Epidote replacement on plagioclase | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Phyllosilacate (single crystal) | 7 | 15 | 23 | 37 | 34 | 42 | 14 | 12 | 16 | 15 | 5 | 3 | – | – | – | – |
| Phyllosilacate in metamorphic r.f. | – | 4 | – | 3 | 6 | 4 | 8 | 4 | 8 | – | – | – | 8 | 4 | 1 | – |
| Phyllosilacate in plutonic r.f. | – | – | – | – | – | – | – | 6 | – | – | 2 | – | – | – | – | – |
| Phyllosilacate in plutonic or gneissic r.f. | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Phyllosilacate in volcanic r.f. | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Chlorite | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Lithic fragments | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Volcanic lithic with microlitic texture | – | – | – | – | – | – | – | 3 | – | – | – | – | – | – | – | – |
| Volcanic lithic with lathwork texture | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Volcanic lithic with vitric texture | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Volcanic lithic with felsitic granular texture | – | – | 1 | – | – | – | – | 7 | – | – | – | – | – | – | – | – |
| Volcanic lithic with felsitic seriate texture | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Serpentinite schist | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Slate lithic fragment | – | | – | – | – | – | – | 9 | – | 6 | – | – | 1 | – | – | – |
| Phyllite lithic fragment | – | 7 | 4 | 17 | 12 | 14 | 15 | 6 | 28 | 12 | 5 | 7 | 32 | – | – | – |
| Fine grained micaschist lithic fragment | – | 15 | 5 | 6 | 12 | 22 | 11 | 8 | 10 | 13 | 4 | 2 | – | – | – | – |
| Chlorite-schist lithic fragment | 11 | – | – | – | – | 4 | – | – | – | – | – | – | – | – | – | – |
| Amphibolite lithic fragment | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Epidote-schist litic fragment | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Shale lithic fragment | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Impure chert | – | – | – | 2 | – | – | – | – | – | – | – | – | – | – | – | – |
| Siltstone | 3 | – | – | – | – | – | 3 | 1 | – | 1 | – | 2 | – | – | – | – |
| Micaschist | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Neo Volcanic | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Quartz in neovolcanic r.f. | – | – | – | – | – | – | – | – | – | – | – | – | – | 0 | 8 | 2 |
| Plagioclase single euhedral | – | – | – | – | – | – | – | – | – | – | – | – | – | 2 | 3 | 33 |
| K-feldspar single euhedral | – | – | – | – | – | – | – | – | – | – | – | – | – | 11 | 7 | 0 |
| Plagioclase in neovolcanic | – | – | – | – | – | – | – | – | – | – | – | – | – | 5 | 3 | 45 |
| K-feldspar in neovolcanic | – | – | – | – | – | – | – | – | – | – | – | – | – | 3 | – | 2 |
| Phyllosilicate in neovolcanic r.f. | – | – | – | – | – | – | – | – | – | – | – | – | – | 0 | – | 0 |
| Volcanic lithic with microlitic texture | – | – | – | – | – | – | – | – | – | – | – | – | – | 16 | 4 | 52 |
| Volcanic lithic with lathwork texture | – | – | – | – | – | – | – | – | – | – | – | – | – | 0 | – | 9 |
| Volcanic lithic with vitric texture | – | – | – | – | – | – | – | – | – | – | – | – | – | 279 | 325 | – |
| Volcanic lithic with felsitic granular texture | – | – | – | – | – | – | – | – | – | – | – | – | – | 46 | 10 | – |
| Volcanic lithic with felsitic seriate texture | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | 11 |
| Brown Glasses | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Colourless | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Biotite in neovolcanic | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Pumice and shard fragments | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Vitric pumice | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Dense neovolcanic | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Dense minerals | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Dense mineral (single crystal) | – | – | – | – | – | – | – | – | – | – | – | – | – | 1 | – | 2 |
| Apathite (single crystal) | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Tourmaline (single crystal) | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Horneblende (single crystal) | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Piroxene (single crystal) | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Rutile (single crystal) | – | – | 1 | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Neovolcanic horneblende (single crystal) | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | 18 |
| Titanite (single crystal) | – | – | 3 | 3 | – | – | – | 7 | – | – | – | – | 1 | – | – | – |
| Epidote (single crystal) | 24 | 34 | 22 | 17 | 1 | – | 3 | 1 | – | – | – | – | 1 | – | – | – |
| Zircon (single crystal) | – | – | – | – | 1 | – | – | – | – | – | – | – | – | – | – | – |
| Granat (single crystal) | – | – | 1 | 2 | – | 4 | – | – | – | – | 4 | – | – | – | – | – |
| Neovolcanic piroxene (singolo cristallo) | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | 2 |
| Epidote in metamorphic r.f. | 1 | 20 | – | – | – | – | 2 | 1 | – | – | – | – | – | – | – | – |
| Horneblende in plutonic r.f. | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Horneblende in neovulcanic r.f. | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Titanite in plutonic r.f. | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Epidote in plutonic r.f. | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Zircon in plutonic r.f. | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Granat in metamorphic r.f. | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Amphibole in metamorphic r.f. | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Piroxene in neovolcanic r.f. | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Epidote in neovolcanic r.f. | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Dense mineral in neovolcanic r.f. | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Opaque minerals | – | – | 2 | – | 5 | – | 2 | – | 1 | – | – | – | – | – | – | 8 |
| Amphibole (single crystal) | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Calcite replacement on epidote | 3 | – | – | – | 1 | – | – | – | – | – | – | – | – | – | – | – |
| CE | | | | | | | | | | | | | | | | |
| Micritic limestone | – | – | – | – | – | – | 1 | 2 | – | – | – | – | 9 | – | – | 23 |
| Sparitic limestone | – | – | 1 | – | – | – | – | 1 | – | – | – | – | – | – | – | 4 |
| Biosparitic limestone | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | 1 |
| Biomicritic limestone | – | – | – | – | – | – | – | – | – | – | – | – | 4 | – | – | 28 |
| Fossil (single skeleton) | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Single spar (calcite) | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Foliated limestone | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | 3 |
| Silty-arenitic limestone | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| CI | | | | | | | | | | | | | | | | |
| Bioclast | – | – | – | – | – | – | – | – | – | – | – | – | 1 | – | – | 25 |
| Intraclast | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| NCI | | | | | | | | | | | | | | | | |
| Glauconite | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | 1 |
| Rip-up clasts | – | – | – | – | – | – | – | – | – | – | 1 | – | – | – | – | – |
| Oxid-fe | – | – | – | – | – | – | – | 3 | – | – | – | – | – | – | – | – |
| Mx | | | | | | | | | | | | | | | | |
| Siliciclastic matrix | 76 | 14 | 38 | 110 | 32 | 38 | 10 | 7 | 65 | 64 | – | 16 | – | – | – | – |
| Carbonate matrix | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Volcaniclastic matrix | – | – | 25 | – | – | – | – | – | – | – | – | – | – | 107 | 80 | 26 |
| Pseudo-matrix | – | 7 | – | 3 | 8 | – | – | – | – | – | – | – | – | – | – | – |
| Cm | | | | | | | | | | | | | | | | |
| Carbonate cement (pore-filling) | 5 | – | 3 | – | 6 | – | 2 | – | 5 | 2 | 38 | 61 | 2 | – | – | – |
| Carbonate cements (patchy calcite) | 2 | – | 3 | – | 13 | – | – | 145 | 2 | 7 | 50 | 4 | 9 | – | – | – |
| Siliceous cement | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Phyllosilicate cement | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | 4 |
| Oxid-fe cement | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Siliceous cement | – | – | – | – | – | – | – | – | – | – | – | – | – | 14 | 3 | – |
| Kaolinite cement | – | – | – | – | – | – | – | – | 74 | 56 | – | – | – | – | – | – |
| Quartz overgrowth | – | 1 | – | – | – | – | – | – | – | – | – | – | 2 | – | – | – |
| Calcite replacement on undetermined grain | 3 | – | 7 | – | 9 | – | 6 | 6 | 4 | – | – | 19 | 145 | 22 | 7 | 75 |
| Clay and clay grain coats | – | – | – | – | – | – | – | – | – | – | – | – | 17 | – | – | 0 |
| Undetermined grain | – | – | 1 | – | – | – | 2 | 1 | – | – | – | – | – | – | – | – |
| Alterite | 1 | 2 | – | 1 | 3 | – | – | 2 | – | 5 | – | – | – | 9 | 17 | 3 |
| Undeterminate | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| N= | 549 | 520 | 535 | 516 | 476 | 482 | 489 | 505 | 534 | 507 | 503 | 518 | 580 | 552 | 496 | 382 |

| | SC-800 | SC-801 | SC-802 | SC-803 | SC-805 | SC-807 | SC-808 | SC-809 | SC-810 | SC-811 | SC-812 | SC-813 | SC-815 | SC-816 | SC-817 | SC-819 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| NCE | | | | | | | | | | | | | | | | |
| Quartz (single crystal) | 9 | 4 | 42 | 92 | 78 | 104 | 112 | 74 | 96 | 123 | 24 | 36 | 124 | 108 | 103 | 104 |
| Polycrystalline quartz with tectonic fabric | 4 | – | 2 | 2 | 8 | 6 | 3 | 2 | 8 | 26 | 73 | 19 | 9 | 8 | 28 | 33 |
| Polycrystalline quartz without tectonic fabric | 7 | 5 | 8 | 1 | 2 | 3 | 6 | – | 3 | 3 | 4 | 3 | 4 | 3 | – | – |
| Quartz in volcanic r.f. | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Quartz in metamorphic r.f. | 6 | 2 | 28 | 107 | 49 | 31 | 76 | 34 | 25 | 52 | 32 | 35 | 72 | 142 | 49 | 43 |
| Quartz in plutonic r.f. | – | – | – | 2 | 15 | 8 | 3 | 12 | 3 | 2 | 1 | 1 | 6 | 6 | 8 | 18 |
| Quartz in plutonic or gneissic r.f. | – | – | – | – | – | 4 | 1 | 2 | – | 8 | 1 | 12 | 4 | 4 | 15 | 6 |
| Quartz in sandstones | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Calcite replacement on quartz | – | – | – | 1 | 4 | – | – | – | – | – | – | – | – | 3 | – | – |
| Epidote replacement on quartz | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| K-feldspar (single crystal) | 4 | 4 | 22 | 72 | 81 | 76 | 55 | 67 | 94 | 15 | – | 5 | 61 | 13 | 2 | 7 |

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| K-feldspar in volcanic r.f. | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| K-feldspar in metamorphic r.f. | – | – | 1 | 12 | 9 | 11 | 5 | – | 8 | 3 | 1 | 4 | 3 | 2 | – | – |
| K-feldspar in plutonic r.f | – | – | – | 5 | 11 | 3 | 2 | 14 | 4 | 5 | – | – | – | – | – | – |
| K-feldspar in plutonic or gneissic r.f. | – | – | 1 | – | – | – | 1 | – | – | 6 | – | 5 | – | – | 1 | 1 |
| Calcite replacement on K-feldspar | – | – | – | – | – | – | 2 | – | – | – | – | – | 11 | – | 1 | – |
| Calcite replacement on undetermined K-feldspar | – | – | 5 | – | – | – | – | – | – | – | – | – | – | 1 | – | – |
| Plagioclase (single crystal) | 18 | 152 | 170 | 93 | 102 | 132 | 134 | 126 | 124 | 83 | – | 29 | 69 | 27 | 24 | 47 |
| Plagioclase in metamorphic r.f. | 2 | 1 | 30 | 4 | 5 | 9 | 28 | 18 | 4 | 10 | – | 26 | 6 | 4 | 3 | 8 |
| Plagioclase in plutonic r.f. | – | 3 | 2 | 2 | 9 | 3 | 1 | 41 | 14 | 10 | – | 2 | 8 | 1 | 12 | 26 |
| Plagioclase in plutonic or gneissic r.f. | – | – | 3 | – | – | – | – | – | – | 36 | – | 34 | 5 | – | 9 | 7 |
| Calcite replacement on plagioclase | – | 1 | 12 | – | – | – | 13 | – | – | – | – | – | 9 | – | 1 | – |
| Calcite replacement on undeterminate feldspar | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Epidote replacement on plagioclase | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Phyllosilacate (single crystal) | – | 9 | 19 | 19 | 11 | 7 | 40 | 45 | 16 | 5 | – | – | 13 | 4 | – | – |
| Phyllosilacate in metamorphic r.f. | – | – | | – | – | – | – | 1 | 4 | 20 | 3 | 7 | 5 | 8 | – | 4 |
| Phyllosilacate in plutonic r.f. | – | – | 1 | – | – | – | – | 3 | – | – | – | – | – | – | – | – |
| Phyllosilacate in plutonic or gneissic r.f. | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Phyllosilacate in volcanic r.f. | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Chlorite | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Lithic fragments | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Volcanic lithic with microlitic texture | – | – | 1 | – | – | – | – | – | – | – | – | – | – | – | – | 1 |
| Volcanic lithic with lathwork texture | – | – | | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Volcanic lithic with vitric texture | – | – | 28 | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Volcanic lithic with felsitic granular texture | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Volcanic lithic with felsitic seriate texture | – | – | – | – | – | – | – | – | – | – | 1 | – | – | – | – | – |
| Serpentinite schist | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Slate lithic fragment | – | – | – | – | – | – | – | – | – | 6 | 34 | 14 | – | – | 7 | – |
| Phyllite lithic fragment | – | – | 13 | 8 | 3 | 11 | 9 | 4 | 4 | 64 | 258 | 199 | – | 35 | 137 | 80 |
| Fine grained micaschist lithic fragment | – | – | 25 | 47 | 27 | 8 | 2 | 12 | 2 | – | – | 5 | – | 31 | – | – |
| Chlorite-schist lithic fragment | – | – | – | 8 | 9 | – | – | 3 | – | – | – | – | – | – | – | – |
| Amphibolite lithic fragment | – | – | – | – | – | – | – | – | – | – | – | 8 | – | – | – | – |
| Epidote-schist litic fragment | – | – | – | – | – | – | – | – | – | – | – | 8 | – | – | – | – |
| Shale lithic fragment | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Impure chert | – | – | 5 | – | – | – | – | – | – | – | 7 | – | – | – | – | – |
| Siltstone | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Micaschist | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Neo Volcanic | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Quartz in neovolcanic r.f. | 6 | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Plagioclase single euhedral | 42 | 9 | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| K-feldspar single euhedral | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Plagioclase in neovolcanic | 39 | 5 | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| K-feldspar in neovolcanic | 7 | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Phyllosilicate in neovolcanic r.f. | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Volcanic lithic with microlitic texture | 63 | 112 | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Volcanic lithic with lathwork texture | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Volcanic lithic with vitric texture | 37 | 35 | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Volcanic lithic with felsitic granular texture | 8 | 3 | – | – | – | – | – | – | – | – | – | – | – | – | – | – |

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| Volcanic lithic with felsitic seriate texture | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Brown Glasses | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Colourless | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Biotite in neovolcanic | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Pumice and shard fragments | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Vitric pumice | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Dense neovolcanic | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Dense minerals | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Dense mineral (single crystal) | – | – | – | – | – | – | – | – | – | 2 | – | – | – | – | – | – |
| Apathite (single crystal) | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Tourmaline (single crystal) | 5 | 2 | 1 | – | 4 | – | – | – | – | – | – | – | – | – | – | – |
| Horneblende (single crystal) | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Piroxene (single crystal) | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Rutile (single crystal) | – | – | 1 | – | – | – | – | 1 | – | – | – | – | – | – | – | – |
| Neovolcanic horneblende (single crystal) | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Titanite (single crystal) | 4 | 10 | 1 | – | – | 2 | – | 1 | – | 7 | – | 2 | – | – | – | – |
| Epidote (single crystal) | 2 | 8 | – | 13 | – | – | 1 | 1 | – | 6 | – | 4 | – | – | – | 2 |
| Zircon (single crystal) | 7 | 2 | – | – | 4 | 3 | 1 | – | – | 1 | – | – | – | – | – | – |
| Granat (single crystal) | – | – | 1 | – | – | – | 1 | – | – | – | – | – | – | – | – | – |
| Neovolcanic piroxene (singolo cristallo) | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Epidote in metamorphic r.f. | – | – | – | – | – | – | – | – | – | – | – | 1 | – | – | – | – |
| Horneblende in plutonic r.f. | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Horneblende in neovulcanic r.f. | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Titanite in plutonic r.f. | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Epidote in plutonic r.f. | – | – | – | – | – | – | – | – | – | 1 | – | 1 | – | – | – | – |
| Zircon in plutonic r.f. | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Granat in metamorphic r.f. | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Amphibole in metamorphic r.f. | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Piroxene in neovolcanic r.f. | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Epidote in neovolcanic r.f. | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Dense mineral in neovolcanic r.f. | – | – | – | – | – | – | – | – | – | – | – | 3 | – | – | – | – |
| Opaque minerals | 13 | – | – | – | – | – | – | – | – | – | 4 | – | – | – | 1 | – |
| Amphibole (single crystal) | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Calcite replacement on epidote | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| CE | | | | | | | | | | | | | | | | |
| Micritic limestone | 4 | – | 11 | 17 | 22 | 6 | – | – | – | 2 | – | – | – | – | – | – |
| Sparitic limestone | 1 | – | 10 | | 4 | | – | – | – | – | – | – | – | – | – | – |
| Biosparitic limestone | 1 | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Biomicritic limestone | 5 | – | – | – | – | – | – | – | – | – | – | 1 | – | – | – | – |
| Fossil (single skeleton) | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Single spar (calcite) | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Foliated limestone | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Silty-arenitic limestone | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| CI | | | | | | | | | | | | | | | | |
| Bioclast | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Intraclast | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| NCI | | | | | | | | | | | | | | | | |
| Glauconite | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rip-up clasts | – | – | – | – | – | – | – | – | – | – | 3 | – | – | – | – | – |
| Oxid-fe | – | 13 | 1 | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Mx | | | | | | | | | | | | | | | | |
| Siliciclastic matrix | – | 5 | 68 | 16 | 11 | 17 | 16 | 43 | 82 | – | – | – | 32 | 8 | 6 | 86 |
| Carbonate matrix | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Volcaniclastic matrix | – | 4 | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Pseudo-matrix | – | – | – | – | – | – | – | 2 | – | – | – | – | – | – | – | – |
| Cm | | | | | | | | | | | | | | | | |
| Carbonate cement (pore-filling) | – | 144 | 2 | 43 | 2 | 4 | 11 | – | – | – | – | – | 3 | 8 | – | – |
| Carbonate cements (patchy calcite) | – | 5 | – | – | 102 | 23 | 1 | – | – | – | – | – | 58 | 104 | 8 | 23 |
| Siliceous cement | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Phyllosilicate cement | 6 | – | – | – | – | – | – | – | – | 6 | 2 | 8 | – | – | – | – |
| Oxid-fe cement | – | – | – | – | – | – | – | – | – | – | 29 | – | – | – | – | – |
| Siliceous cement | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Kaolinite cement | – | – | – | – | – | – | – | – | – | – | – | – | – | 16 | – | – |
| Quartz overgrowth | – | – | – | – | – | – | 1 | – | – | 4 | – | 1 | – | – | – | – |
| Calcite replacement on undetermined grain | 24 | 5 | 12 | – | – | – | 2 | 3 | – | 2 | – | 3 | – | – | 35 | 42 |
| Clay and clay grain coats | – | – | – | – | – | – | – | – | – | 1 | 15 | – | – | – | 122 | – |
| Undetermined grain | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Alterite | – | 8 | 18 | 2 | – | – | – | 3 | – | 3 | – | – | – | – | – | 3 |
| Undeterminate | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| N= | 324 | 551 | 544 | 566 | 572 | 471 | 527 | 512 | 491 | 512 | 492 | 476 | 502 | 536 | 572 | 541 |

| | SC-820 | SC-821 | SC-822 | SC-823 | SC-824 | SC-825 | SC-826 | SC-827 | SC-828 | SC-829 |
|---|---|---|---|---|---|---|---|---|---|---|
| NCE | | | | | | | | | | |
| Quartz (single crystal) | 94 | 115 | 92 | 86 | 66 | 80 | 73 | 74 | 84 | 47 |
| Polycrystalline quartz with tectonic fabric | 13 | 4 | 13 | 6 | 5 | – | 11 | 9 | 16 | 1 |
| Polycrystalline quartz without tectonic fabric | 1 | – | 3 | – | – | – | – | – | 1 | – |
| Quartz in volcanic r.f. | – | – | – | – | – | – | – | – | – | – |
| Quartz in metamorphic r.f. | 95 | 30 | 56 | 95 | 68 | 31 | 58 | 76 | 79 | 125 |
| Quartz in plutonic r.f. | 13 | 5 | 2 | 5 | 11 | 9 | 14 | 2 | 2 | 35 |
| Quartz in plutonic or gneissic r.f. | 14 | 12 | 10 | 18 | 24 | 38 | 50 | 52 | 43 | 11 |
| Quartz in sandstones | – | – | – | – | – | – | – | – | – | – |
| Calcite replacement on quartz | – | 4 | – | – | – | – | – | – | – | 6 |
| Epidote replacement on quartz | – | – | – | – | – | – | – | – | – | – |
| K-feldspar (single crystal) | 19 | 16 | 39 | 40 | 26 | 55 | 26 | 18 | 14 | 41 |
| K-feldspar in volcanic r.f. | – | – | – | – | – | – | – | – | – | – |
| K-feldspar in metamorphic r.f. | 3 | – | 6 | 10 | 2 | 0 | 0 | 3 | 4 | 16 |
| K-feldspar in plutonic r.f | 6 | 1 | 0 | 3 | 1 | 0 | 3 | 1 | 0 | 9 |
| K-feldspar in plutonic or gneissic r.f. | 35 | 7 | 24 | 59 | 18 | 22 | 20 | 30 | 26 | 7 |
| Calcite replacement on K-feldspar | – | 1 | – | – | – | – | – | – | – | 13 |
| Calcite replacement on undetermined K- | – | – | – | – | – | – | – | – | – | 5 |

| feldspar | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Plagioclase (single crystal) | 50 | 36 | 69 | 56 | 44 | 94 | 33 | 35 | 44 | 58 |
| Plagioclase in metamorphic r.f. | 12 | 4 | 8 | 9 | 8 | 1 | 5 | 7 | 6 | 28 |
| Plagioclase in plutonic r.f. | 7 | 2 | 3 | 10 | 5 | 2 | 6 | 1 | 1 | 6 |
| Plagioclase in plutonic or gneissic r.f. | 42 | 17 | 60 | 122 | 87 | 78 | 110 | 83 | 79 | 7 |
| Calcite replacement on plagioclase | – | 3 | 1 | – | – | – | – | – | 9 | 24 |
| Calcite replacement on undeterminate feldspar | – | – | – | – | – | – | – | – | – | – |
| Epidote replacement on plagioclase | – | – | – | – | – | – | – | – | – | – |
| Phyllosilacate (single crystal) | – | 2 | – | 1 | – | – | – | – | 9 | 3 |
| Phyllosilacate in metamorphic r.f. | 3 | 33 | 41 | 3 | 0 | 0 | 1 | 6 | 12 | 12 |
| Phyllosilacate in plutonic r.f. | – | – | – | – | – | – | – | – | – | – |
| Phyllosilacate in plutonic or gneissic r.f. | 1 | – | – | – | – | – | – | – | – | – |
| Phyllosilacate in volcanic r.f. | – | – | – | – | – | – | – | – | – | – |
| Chlorite | – | – | – | – | – | – | – | – | – | – |
| Lithic fragments | – | – | – | – | – | – | – | – | – | – |
| Volcanic lithic with microlitic texture | – | – | – | – | – | – | – | – | – | – |
| Volcanic lithic with lathwork texture | – | – | – | – | – | – | – | – | – | – |
| Volcanic lithic with vitric texture | – | – | – | – | – | – | – | – | – | – |
| Volcanic lithic with felsitic granular texture | – | – | – | – | – | – | – | – | – | – |
| Volcanic lithic with felsitic seriate texture | – | – | – | – | – | – | – | – | – | – |
| Serpentinite schist | – | – | – | – | – | – | – | – | – | – |
| Slate lithic fragment | – | – | – | – | – | – | – | 4 | 4 | – |
| Phyllite lithic fragment | 42 | 27 | 28 | 8 | 78 | 7 | 0 | 10 | 16 | 5 |
| Fine grained micaschist lithic fragment | – | – | – | – | – | – | – | – | – | – |
| Chlorite-schist lithic fragment | – | – | – | – | – | – | – | – | – | – |
| Amphibolite lithic fragment | – | – | – | – | – | – | – | – | – | – |
| Epidote-schist litic fragment | – | – | – | – | – | – | – | – | – | – |
| Shale lithic fragment | – | – | – | – | – | – | – | – | – | – |
| Impure chert | – | – | – | – | – | – | – | – | – | – |
| Siltstone | – | – | – | – | – | – | – | – | – | – |
| Micaschist | – | – | – | – | – | – | – | – | – | – |
| Neo Volcanic | – | – | – | – | – | – | – | – | – | – |
| Quartz in neovolcanic r.f. | – | – | – | – | – | – | – | – | – | – |
| Plagioclase single euhedral | – | – | – | – | – | – | – | – | – | – |
| K-feldspar single euhedral | – | – | – | – | – | – | – | – | – | – |
| Plagioclase in neovolcanic | – | – | – | – | – | – | – | – | – | – |
| K-feldspar in neovolcanic | – | – | – | – | – | – | – | – | – | – |
| Phyllosilicate in neovolcanic r.f. | – | – | – | – | – | – | – | – | – | – |
| Volcanic lithic with microlitic texture | – | – | – | – | – | – | – | – | – | – |
| Volcanic lithic with lathwork texture | – | – | – | – | – | – | – | – | – | – |
| Volcanic lithic with vitric texture | – | – | – | – | – | – | – | – | – | – |
| Volcanic lithic with felsitic granular texture | – | – | – | – | – | – | – | – | – | – |
| Volcanic lithic with felsitic seriate texture | – | – | – | – | – | – | – | – | – | – |
| Brown Glasses | – | – | – | – | – | – | – | – | – | – |
| Colourless | – | – | – | – | – | – | – | – | – | – |
| Biotite in neovolcanic | – | – | – | – | – | – | – | – | – | – |
| Pumice and shard fragments | – | – | – | – | – | – | – | – | – | – |
| Vitric pumice | – | – | – | – | – | – | – | – | – | – |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Dense neovolcanic | – | – | – | – | – | – | – | – | – | – |
| Dense minerals | – | – | – | – | – | – | – | – | – | – |
| Dense mineral (single crystal) | 1 | 1 | 1 | – | – | 2 | – | 2 | – | – |
| Apathite (single crystal) | – | – | – | – | – | – | – | – | – | – |
| Tourmaline (single crystal) | – | – | – | – | – | – | – | – | – | – |
| Horneblende (single crystal) | – | – | – | – | – | – | – | – | – | – |
| Piroxene (single crystal) | – | – | – | – | – | – | – | – | – | – |
| Rutile (single crystal) | – | – | – | – | – | – | – | – | – | – |
| Neovolcanic horneblende (single crystal) | – | – | – | – | – | – | – | – | – | – |
| Titanite (single crystal) | 1 | 0 | 2 | 2 | – | – | – | – | – | – |
| Epidote (single crystal) | – | 0 | 3 | 1 | 0 | 2 | – | – | 2 | – |
| Zircon (single crystal) | – | 1 | – | 1 | 0 | 1 | 2 | 1 | 5 | – |
| Granat (single crystal) | – | 3 | – | 1 | 2 | 5 | 1 | – | – | – |
| Neovolcanic piroxene (singolo cristallo) | – | – | – | – | – | – | – | – | – | – |
| Epidote in metamorphic r.f. | – | – | – | – | – | – | – | – | – | – |
| Horneblende in plutonic r.f. | – | – | – | – | – | – | – | – | – | – |
| Horneblende in neovulcanic r.f. | – | – | – | – | – | – | – | – | – | – |
| Titanite in plutonic r.f. | – | – | – | – | – | – | – | – | – | – |
| Epidote in plutonic r.f. | – | – | – | – | – | – | – | – | – | – |
| Zircon in plutonic r.f. | – | – | – | – | – | – | – | – | – | – |
| Granat in metamorphic r.f. | – | – | – | – | – | – | – | – | – | – |
| Amphibole in metamorphic r.f. | – | – | – | – | – | – | – | – | – | – |
| Piroxene in neovolcanic r.f. | – | – | – | – | – | – | – | – | – | – |
| Epidote in neovolcanic r.f. | – | – | – | – | – | – | – | – | – | – |
| Dense mineral in neovolcanic r.f. | – | – | – | – | – | – | – | – | – | – |
| Opaque minerals | – | 1 | – | – | – | – | – | 2 | – | – |
| Amphibole (single crystal) | – | – | – | – | – | – | – | – | – | – |
| Calcite replacement on epidote | – | – | – | – | – | – | – | – | – | – |
| CE | | | | | | | | | | |
| Micritic limestone | – | 10 | 1 | – | – | – | – | – | – | – |
| Sparitic limestone | – | – | – | – | – | – | – | – | – | 1 |
| Biosparitic limestone | – | – | – | – | – | – | – | – | – | – |
| Biomicritic limestone | – | – | – | – | – | – | – | – | – | – |
| Fossil (single skeleton) | – | – | – | – | – | – | – | – | – | – |
| Single spar (calcite) | – | – | – | – | – | – | – | – | – | – |
| Foliated limestone | 1 | 2 | – | – | – | – | – | – | – | – |
| Silty-arenitic limestone | – | – | – | – | – | – | – | – | – | – |
| CI | | | | | | | | | | |
| Bioclast | – | 2 | – | – | – | – | – | – | – | – |
| Intraclast | – | – | – | – | – | – | – | – | – | – |
| NCI | | | | | | | | | | |
| Glauconite | – | 1 | – | – | – | – | – | – | – | – |
| Rip-up clasts | – | – | – | – | – | – | – | – | – | – |
| Oxid-fe | – | – | – | – | – | – | – | – | – | – |
| Mx | | | | | | | | | | |
| Siliciclastic matrix | 62 | 120 | 40 | 14 | 54 | 93 | 67 | 10 | 73 | 24 |
| Carbonate matrix | – | – | – | – | – | – | – | – | – | – |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Volcaniclastic matrix | – | – | – | – | – | – | – | – | – | – |
| Pseudo-matrix | – | – | – | – | – | – | – | – | – | 3 |
| Cm | | | | | | | | | | |
| Carbonate cement (pore-filling) | – | – | – | – | – | – | – | – | – | – |
| Carbonate cements (patchy calcite) | – | – | – | – | – | – | – | – | – | 2 |
| Siliceous cement | – | – | – | – | – | – | – | – | – | – |
| Phyllosilicate cement | – | 3 | 3 | 13 | – | 42 | 17 | – | – | – |
| Oxid-fe cement | – | 1 | – | – | – | 1 | – | – | – | – |
| Siliceous cement | 1 | – | – | – | – | – | – | – | – | – |
| Kaolinite cement | – | – | – | – | – | – | – | – | – | – |
| Quartz overgrowth | – | – | – | 1 | – | – | 1 | 1 | 1 | 2 |
| Calcite replacement on undetermined grain | 47 | 49 | 64 | – | – | – | – | 78 | – | 16 |
| Clay and clay grain coats | – | – | – | 1 | 8 | – | – | – | 2 | – |
| Undetermined grain | – | – | – | – | – | – | – | – | – | – |
| Alterite | – | – | – | – | – | – | – | – | – | – |
| Undeterminate | – | – | – | – | – | – | – | – | – | – |
| N= | 563 | 513 | 569 | 565 | 507 | 563 | 498 | 505 | 532 | 507 |