International Research Group
South Caucasus Geosciences

PREAMBLE

The Lesser Caucasus so called South Caucasus mountain belt gathering Armenia, Azerbaijan and Georgia countries shows a high potential in Earth Sciences researches due to its geographical location and geological setting. Since these three countries are located on an active Tethyan mountain belt, they appear to be a promising area to focus on several research projects in Earth Sciences topics. Studies can be realized under the best conditions regarding both the quality of the field scientific data and the local scientific knowledge and facilities.
Two main directions of high societal and geological interests can be highlighted. The first one is based on natural resources (ores deposits, hydrocarbons) whereas the second one deals with active tectonics and its consequences on seismic risks.
These two research topics have also academicals objectives aiming to understand tectonic and geodynamical processes of a collision range still active. Moreover, the understanding of this mountain belt will allow defining the first steps of the Mediterranean area evolution. This is the reason why this study is a part of the Mediterranean Program of the French National Institute of Universe Sciences (INSU).
Then, researches in the Lesser Caucasus area allow studying both fundamental and societal stakes which is a good example of finalized researches on Earth Sciences topics.
Since 2003, some fruitful collaborations have been created with Armenia, Azerbaijan, and Georgia inside UMR GeoAzur (funding by MEBE programme - Middle East Basins Evolution- and INTAS), even since 1989 with Armenia inside UMR Geosciences Montpellier (PICS CNRS). Thanks to these collaborations, it is now possible to develop some research objectives fitting with the Mediterranean Program from INSU projects.
In agreement with the research Institute on Earth Sciences in Armenia, Azerbaijan, and Georgia, this is the appropriate time to launch an IRG in order to define the cooperative framework for the four next years. An IRG is an ideal programme to share information, to organise workshops, and to facilitate researcher's mobility.
This international research programme will define an institutional framework on Earth Sciences researches in this geographical area of the world.

ARTICLE 1 – CREATION AND TERM

An International Research Group, a cooperative structure devoid of any legal status, hereinafter referred to as IRG, entitled **South Caucasus Geosciences**, is hereby created by the Parties, for a term of four (4) years.

Creation of IRG should be legalized by means of Agreement signed by the Parties.

The Agreement can be renewed by amendment.

Any decision to renew shall be taken by the Parties following consultation of the Steering Committee and of the Scientific Management Committee.

ARTICLE 2 – MISSION

The **South Caucasus Geosciences** IRG's mission is to coordinate the scientific activities set out in Annex.

For this purpose, the IRG undertakes in particular to:

- facilitate and encourage contacts and exchanges between its members ;
- encourage any collaborative activities ;
- Coordinate and develop multi-partner research programs to respond to calls for tender for research and technological development support ;
- ensure the harmonisation and complementary of the programmes being pursued by workshops, conferences, or any other event devoted to scientific themes that are relevant to the IRG ;
- encourage training actions.

ARTICLE 3 – ORGANISATION

3.1. – CO-ORDINATOR

The Co-ordinator and the assistant Co-ordinators of the IRG, identified in Annex 3, are jointly appointed by the Parties for a term of four (4) years.

The Co-ordinator shall prepare the annual budget of the IRG's activities and submit the GDRE annual scientific report and financial report to the Parties after approval by the Scientific Management Committee.

3.2. – SCIENTIFIC MANAGEMENT COMMITTEE

The IRG Scientific Management Committee shall be composed of one representative from each laboratory or team member of IRG.

The Scientific Management Committee shall be chaired by the co-ordinator.

The Scientific Management Committee shall review the progress of the IRG's activities and ascertain the current status there of. It shall examine the opportunities for joint applications to international joint calls and suggest multilateral research programs. It assesses the staffing and budgetary needs required for the IRG's activities. It shall approve the yearly IRG financial report by a qualified majority of its members.

The Co-ordinator may consult the Scientific Management Committee on any question relative to the IRG.

The Scientific Management Committee shall convene when and as needed, and at least once a year. It shall convene when the Co-ordinator and/or at least one-third of its member teams requests such a meeting. If necessary, said meeting may take place via teleconferencing, subject to unanimous agreement by all members of the Scientific Management Committee.

In case of impediment a member of the Scientific Management Committee can ask to another member to represent him by proxy. No member shall hold more than one proxy.

3.3. – STEERING COMMITTEE

The Parties shall set up a Steering Committee to coordinate and assess the IRG activities. The Steering Committee shall be comprised of representatives of the following Parties who shall not participate in the IRG: CNRS, UNS, UPMC, NAS-RA, ANAS, GNSF.

Representatives of the other Parties may attend the meetings of the Steering Committee without voting right. Each Party which adheres to the IRG shall appoint a full representative to the Steering Committee whenever its originating country had no representative in the Steering Committee before the adhesion of the said Party.

The Steering Committee shall:

- express an opinion as to the scientific and financial reports of the IRG, submitted by the co-ordinator, and as to be the current status of work in progress. It shall suggest adjustments as necessary;

- decide to incorporate new laboratories into the IRG after consulting with the Scientific Management Committee;

- suggest any modification to the Agreement on cooperation between Parties.

The Steering Committee shall meet at least once every two (2) years or at the request of one-quarter of its members. It shall be chaired on a rotating basis by one of its members. It shall appoint one secretary per meeting, in charge of taking minutes of the meeting. The minutes of each meeting shall be subject to approval by the Steering Committee members and shall be distributed to the Parties.

The Steering Committee shall take decisions by a qualified majority of ¾ of the Parties present or represented. Any member of the Steering Committee can ask another member to represent him by proxy. No member shall hold more than one proxy.

The IRG Co-ordinator shall attend the Steering Committee meetings in an advisory capacity.

ARTICLE 4 – FUNDING PROVISIONS

All Parties shall inform the Co-ordinator, prior to the start of every calendar year, of the provisional amount of funds which shall be allocated to the laboratories or teams belonging to the IRG within the scope of the IRG's activities. Each Party shall manage its own funds.

ARTICLE 5 – INTELLECTUAL PROPERTY RIGHTS

5.1. Publications

Publications arising from joint scientific activities of ¨Parties within the scope of the IRG shall include reference to the relevant Parties, and shall mention the support of the IRG. The publication of scientific results shall be made as per the usual custom and practice of the scientific community, with the prior consent of all participants having contributed to the results.

5.2. Nondisclosure

Each Party undertakes to provide to the other Parties any information that could be useful to the completion of activities within the scope of the IRG, inasmuch it is allowed to do so regarding its commitments with third parties.

Throughout the term of the Agreement and for a subsequent period of five (5) years, unless otherwise expressly agreed, the Parties shall refrain from disclosing to any third party or to any other Party any information obtained from another Party within the scope of the Agreement which had been previously designated as confidential by the originating Party.

None of the foregoing is intended to preclude the submission of a thesis to examiners pursuant to the rules and usual practices of the Parties, subject where applicable to the execution of nondisclosure provisions.

In any case, personnel participating to the IRG may still communicate their results in confidential reports to the administrative organization to which they belong.

5.3. Property and exploitation of results

Each Party remains the sole owner of the knowledge, whether patented or not, held prior to the Agreement signed between parties or acquired in parallel with it. The Agreement shall not give any right over the aforementioned knowledge to the others Parties.

All Parties hold a non-transferable right to use the Joint Results they have contributed to free of charge for their own research needs, with the exception of any activity, even free of charge, which is of an industrial or commercial nature.

ANNEX: SCIENTIFIC THEMES

Geodynamic evolution of the Lesser Caucasus mountain belt: Consequences on the natural resources, active tectonics and risks locations.

The Tethyan belt in the Lesser Caucasus (Fig. 1), on which some French teams already work (since 1989 in Armenia for Geosciences Montpellier, since 2003 in Armenia, Azerbaijan and Georgia for GeoAzur) presents a lot of interest for developing Geosciences researches. Indeed this belt is the result of geodynamical processes commonly known all around the world and their interactions with the mantle asthenospheric dynamic. According to new data and previous works made by our South Caucasian colleagues, this belt is the result of oceanisation, subductions, obduction and collision (see publications list). All these processes left witnesses in the belt. Some of them are already discovered. Nevertheless the complexity of the tectonic evolution of the belt has disturbed the structural setting and consequently it is not easy to clearly identify the occurrence of all these geodynamical processes.

In the Lesser Caucasus, a lot of significant works have been already performed particularly before the Soviet Union collapse. Russian and South Caucasian researchers have collected numerous data (geological maps, stratigraphy, petrology) on the Lesser Caucasus belt (Adamia's, Knipper's and Zakariadze's teams for examples). We have taken into account all these previous works and collected new data on the field. Stratigraphic and micropaleontologic data (C. Muller and T. Danelian, Univ. of Lille, France), structural, petrologic geochemical (isotopic analysis, D. Bosch, Univ. of Montpellier) and geochronologic (Ar/Ar : Y. Rolland and M. Corsini, AFT and ZFT : F. Bigot-Cormier, Univ dof Nice-Sophia Antipolis) allow to reconstruct the tectonic evolution since 200 Ma and to propose a new geodynamic model of the evolution of the belt taking into account new conceptual processes of the plate tectonic (slab retreat, delamination, …). The Hervé Philip's and Mireille Perrin's teams of Montpellier have mainly focussed their researches on 1) the active tectonics in order to evaluate the seismic cycle and 2) on the paleomatism.

As the results of this geodynamic evolution is:

- Occurrences in surface of obducted ophiolitic units including resources in gold and chromium
- Sedimentary basins evolution which developed significant potentiality of hydrocarbon (exploited in the Kura Basin, Azerbaijan and Georgia)
- The overthrusting on several tenth kilometres (or more ?) of ophiolitic units on a Gondwanian platform which presents a lot of sedimentological and stratigraphical characteristics of the Arabian Plate (with all that implies in term of source rocks out of hydrocarbons)
- Occurrences of intrusions and volcanic complexes, containing ore deposits (Molybdenum, Gold, Copper), related to the subduction processes
- Occurrence of active faults (Spitak seism in 1988, M : 6.9) related to the Arabian collision with Eurasia
- Evidence of changes in the magnetic field intensity and polarity from the quaternary volcanic rocks in Armenia and Georgia

Thus, Geosciences Montpellier, GeoAzur and local colleagues brought a new vision on the evolution of the Lesser Caucasus and improved acknowledges of the structural framework of both basins and on the mountain belt. Nevertheless, some questions focusing on following topics are still unresolved:

1. Obduction process
2. Genesis along with surface and sub-surface structuration of both basins and chain
3. Origin of syn and post collisional magmatism: interactions between lithosphere and asthenosphere during the main steps of the geodynamical evolution.
4. Location of the recent deformation and active faults according to the structural inheritance.

1. 5.Long-term fluctuations in intensity of the ancient Earth's magnetic field and polarity changes from the paleomagnetic analysis of the Lesser Caucasus volcanic rocks.

Our studies in the IRG programme will be based on these various questions and will allow clarifying and locating some specific areas into the mountain belt which could offer a real potential regarding natural resources (basin: hydrocarbons, magmatism-hydrothermalism: ore deposits) and regarding natural risks (active faults location, seismic cycle).

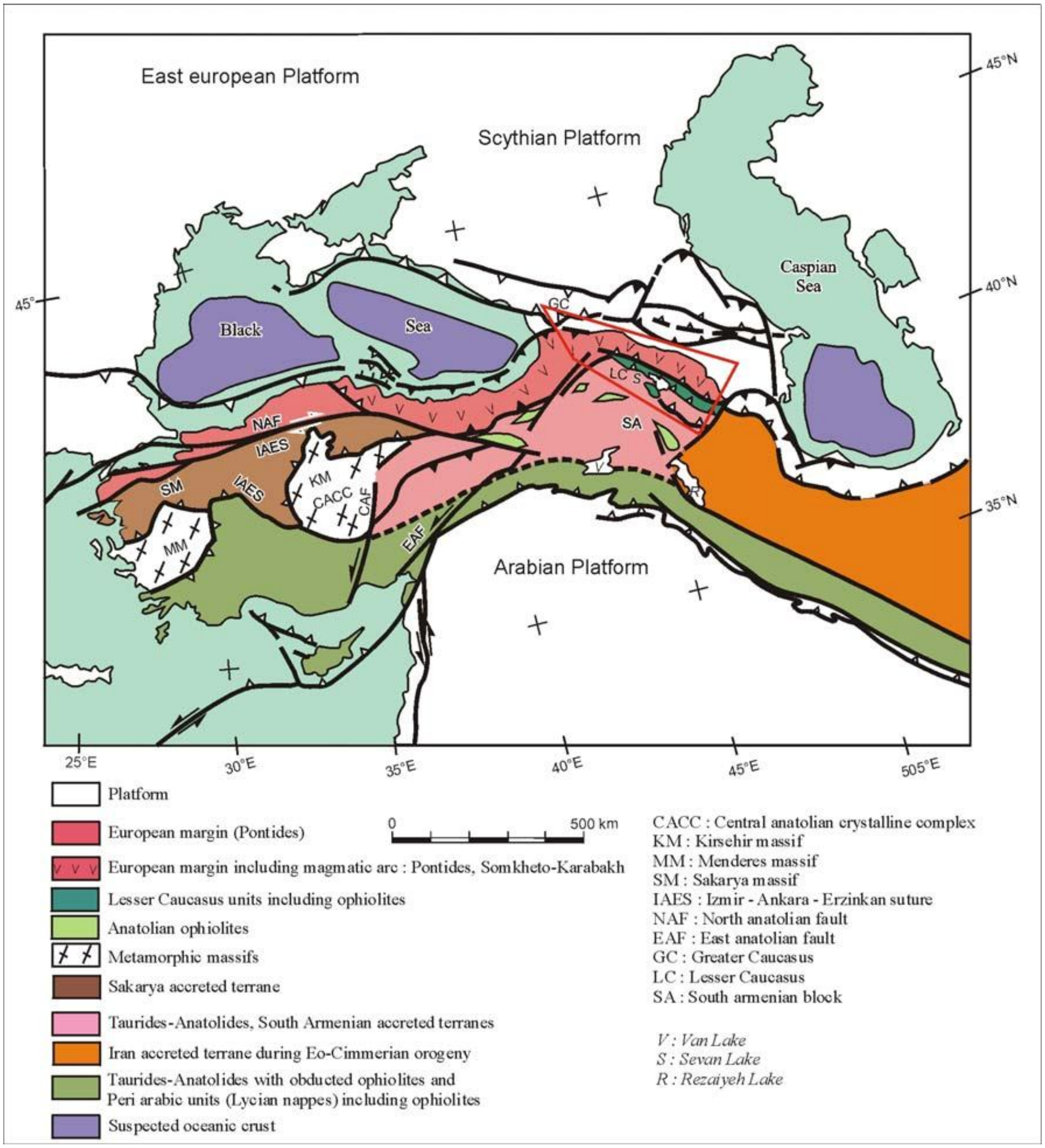

Fig. 1. General structural sketch map showing the studied area (red contours) in the Tethyan belt.

The Lesser Caucasus is located around the Sevan-Akera suture zone, with to the North the Eurasia, and to the South a micro-plate of gondwanian origin (South Armenian Block an eastward extension of the Tauride-Anatolide Block) which collided the Eurasia during Palaeocene-Early Eocene times.

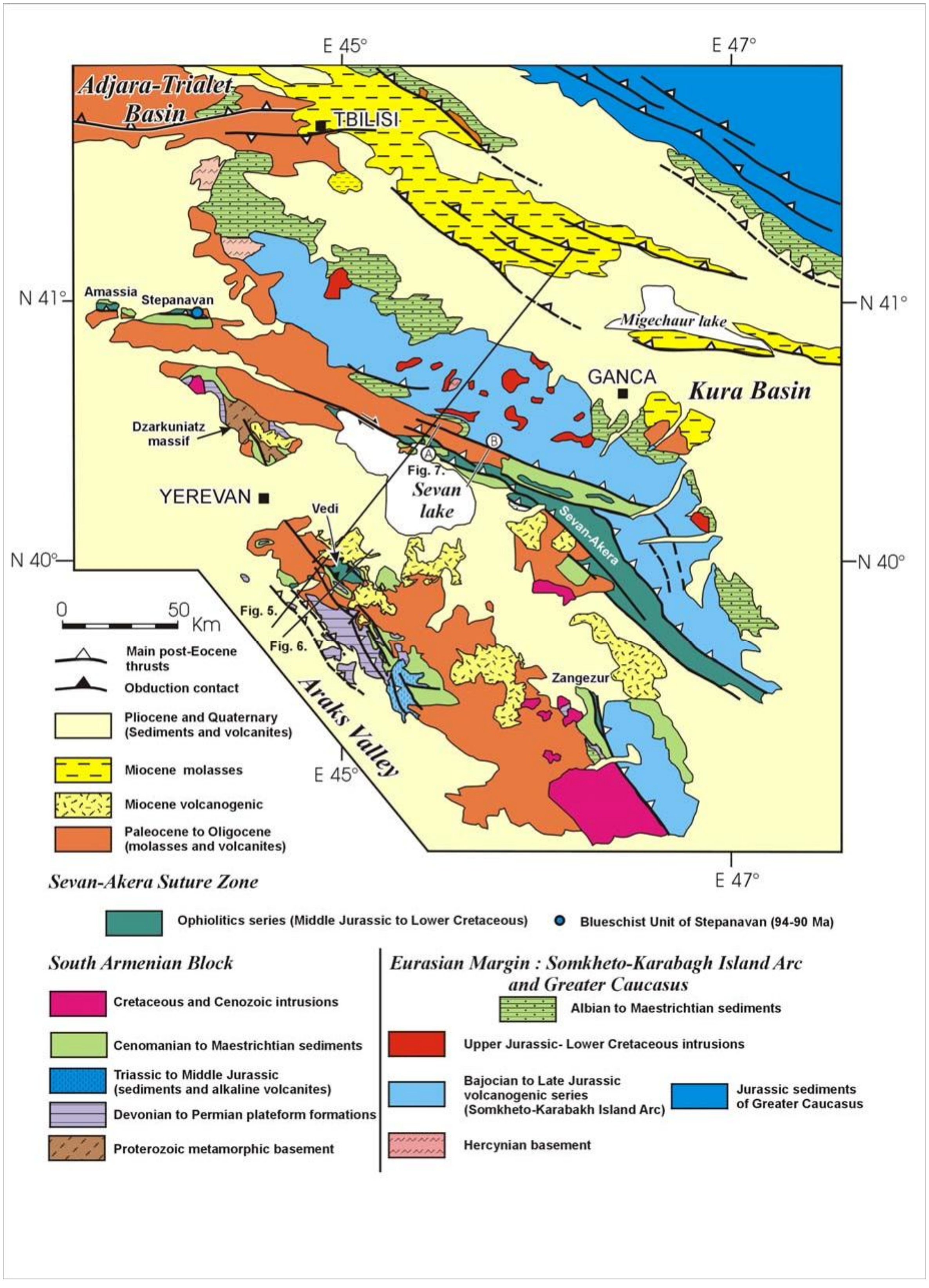

Fig. 2. Structural map of the Lesser Caucasus (Sosson et al., in press).

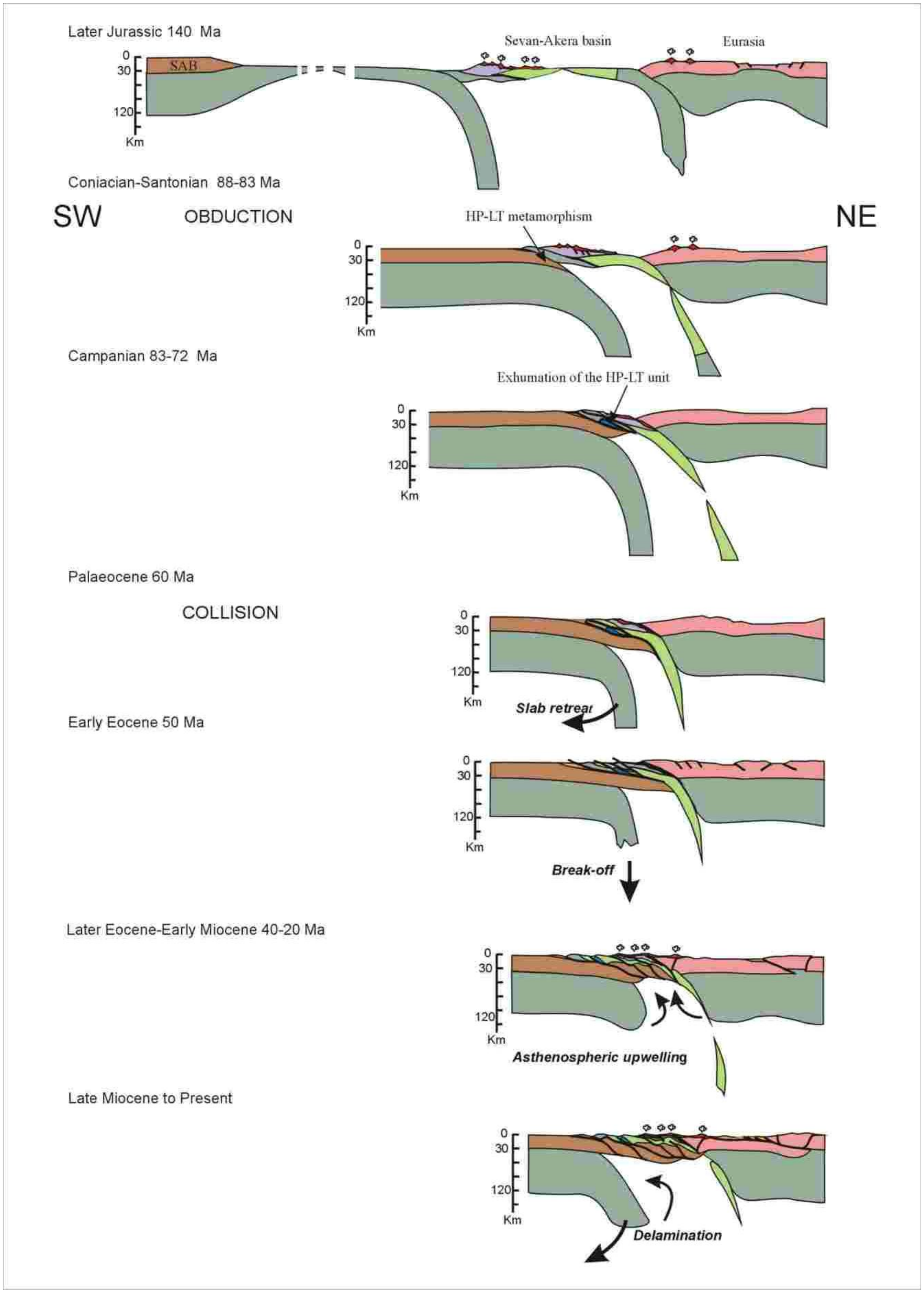

Fig. 3. Geodynamic evolution of the Lesser Caucasus (modified from Sosson et al., in press)

Task 1. Obduction process

Our recent results on the Tethys domain of the Lesser Caucasus mountain belt (Armenia, Azerbaijan, Georgia, see Figs. 2-4), coupled with other studies led in the Middle-East, show that several obductions have occurred within a narrow time range in the Upper Cretaceous. Normally, obductions are rare due to the higher density of oceanic lithosphere with respect to continental one's.

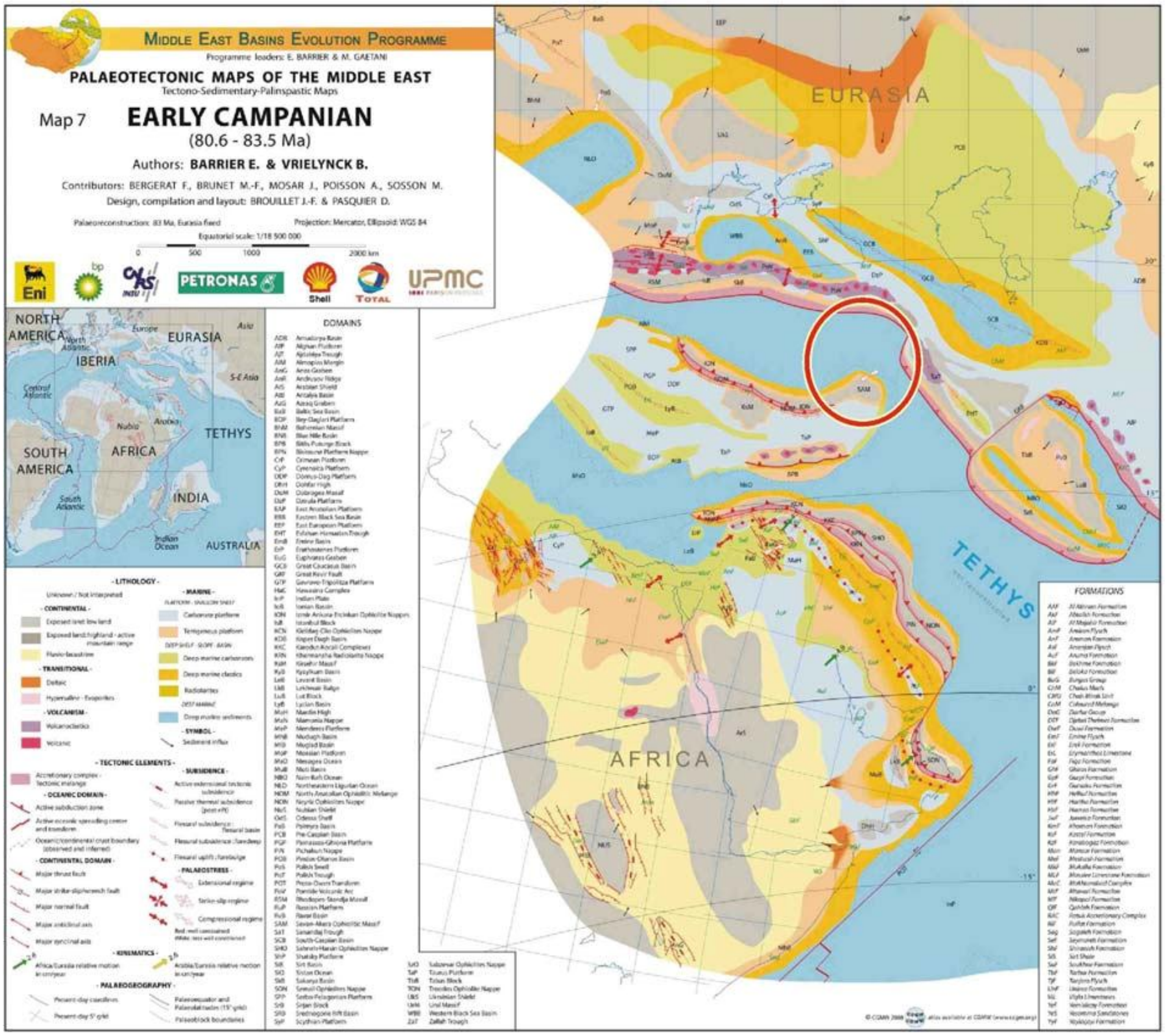

Fig. 4. Campanian paleotectonic map reconstruction of the Middle East (programme MEBE : Middle East Basin Evolution) including the results of our group. End of obduction in the Lesser Caucasus.

One unresolved major scientific question is thus: what is (are) the cause(s) of these obductions?

This question was addressed in several works, and one most accepted view is that the main cause is the acceleration of the Neotethyan oceanic spaces closure in the Middle East (see Agard et al., 2007 for a review). Alternatively, some authors proposed that they might be tied up with intra-oceanic hot-spot related superplumes (Larson, 1991) that have increased the oceanic lithosphere buoyancy, which resulted in its scalping and scrapping-off during oceanic closure (Vaughan and Scarrow, 2003; Stern, 2004). A more straightforward interpretation would be the underthrusting of the continental lithosphere during an intra-oceanic process. But in this case, the intra-oceanic subduction has to be somehow explained. The paleo-tectonic reconstructions undertaken in the frame of the MEBE program (Fig. 4) do not allow responding unequivocally to this question.

Our recent works allow progressing somehow in the debate:

1) First, the Lesser Caucasus ophiolite geochemistry shows that the oceanic lithosphere has MORB compositions slightly contaminated by slab-derived fluids. Geochronological dating provided Jurassic ages. It is overlain by an alkaline sequence, which agrees with an intra-oceanic OIB-type sequence of Lower Cretaceous age; and by an Upper Cretaceous calc-alkaline sequence. Thus, we interpreted the obducted oceanic crust sequence as a three-level crust comprised of a basal oceanic crust formed in a marginal basin, an oceanic island or plateau and an upper section formed in an active volcanic arc context (Galoyan et al., 2007; 2009; Rolland et al., 2009).
2) The Eurasian margin presents a strong magmatic activity between the Bajocian and the Oxfordian and was subject to severe erosion during the Lower Cretaceous (Adamia et al., 1981; Sosson et al., accepted), which we still do not know the cause. It could be due to the active margin uplift while ongoing a compressional phase up to the Coniacian, as sedimentary formations of this age are found unconformably resting on the Upper Jurassic – Lower Cretaceous eroded plutons. Did this huge denudation probably related to compression result from an intra-oceanic seamount or plateau resting on the subducting slab as proposed by Vaughan and Scarrow (2003) in their model?
3) The obduction of the Lesser Caucasus ophiolites over the South Armenian Block is bracketed between the 90 and 83 Ma (Sosson et al., accepted, Fig. 3). But we do not know the exact age of obduction initiation. Available age constraints concern the frontal part of the obduction, where the ophiolites clearly rest on the autochthon of the South Armenian Block. Some of the metamorphic rocks at the back of the obduction system show the presence of a high-temperature metamorphic imprint that could correspond with that of an obducted basal sole (like in the Oman case), but no age has still been obtained.

In summary, we see that in spite of previous works held since 2003, some questions remain, and more work has to be done to precise the timing of obduction and subduction along the active Eurasian margin, and its relationship with mantle dynamics during the Cretaceous.

In addition, the Lesser Caucasus ophiolites comprise major chromium (in the peridotites) and gold (Zod Mine, Armenia) resources. The analysis of their precise locations, at the surface and underground, is essential to unravel further fields in mining exploration. For this, it appears important to study the ore-forming processes but also the precise structure of the ophiolites. This work necessitates some petrographical and geochemical data on the ophiolite rocks, and a detailed tectonic investigation of the obduction structures.

IRG programme on this theme:

– Geological mapping based on existing core data of ophiolites in Armenia. Estimation of the ophiolite units thickness, and their lateral subsurface extension. Integration in a GIS.
– Study of the metamorphic sole (Amassia ophiolites, Armenia). Petrological, structural and geochronological Ar-Ar analyses to decipher the kinematic direction of transport and P-T-t path.
– The Karabagh area remains a poorly investigated zone, where it is important to decipher the structure of the Sevan-Akera suture. Because, there, the suture is less complex, and should give clear and complementary ages on the initial stages of the obduction.
– The analysis of deformation stages during the Lower and Upper Cretaceous of the Eurasian margin (Georgia, Azerbaijan) by thermochronology using fission tracks on zircon and apatite on the Jurassic-Cretaceous plutons of the Eurasian margin. This will lead to estimates of denudation and

uplift rates. These results will be complemented by paleo-stress analysis based on inversion of fault-strea data to infer the paleo-stress field. These results will allow testing Vaughan and Scarrow model concerning the deformation of the active margin.

– Numerical modelling will be undertaken using the ADELI code to analyse the role of a hot-spot to initiate the obduction process, and its role on the compressional stress-field in the active margin.

Task 2 : Basins and Mountain belt structures in surface and subsurface

We obtained new data on the Lesser Caucasus outcrops allowing us to propose a new structural interpretation (Fig. 7) which now require to focus on some significant areas for new investigations.

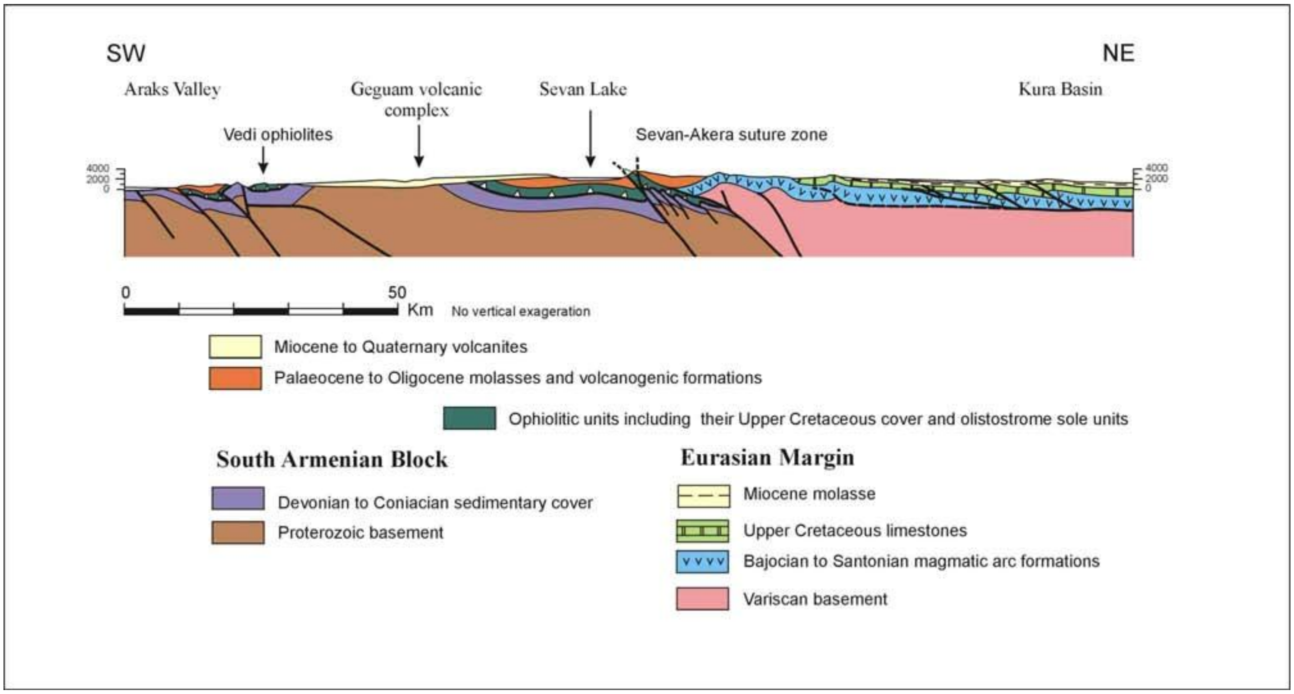

Fig. 5. Cross section of the Lesser Caucasus (Sosson et al., in press), location on Fig. 1 and 2.

On the figure 5, we can see the occurrence of a sedimentary cover (Devonian to Late Cretaceous) of the South Armenian Block beneath the obducted ophiolites from the external domain to the suture zone (Sevan-akera suture zone). Consequently the obdcuted ophiolites over the South Armenian Block are present until the suture zone. These ophiolites cooresponds to an over screen which somewhere allow the outcropping of the autochthon into anticline windows as the result of the collision stages. The previous interpretation (mainly made during the Soviet period) indicates a lot of vertical motion and as the result the ophiolites was assumed to correspond to sutures zones. According to the results of some authors (Aslanyan and Satian, 1977, 1982) there was three suture zones spread on lesser 100 km large all along the mountain belt. As our results shown (Fig. 6) the platform sediments are overthrusted by ophiolites units in front of the belt (Vedi area for example). Consequently the Palaeozoic sources rocks (Devonian-Permian) will be under the ophiolites units. All wells drilled during the soviet period (no more were performed since this period) stopped in the ophiolites.

Moreover the foreland basins in front of the belt are composed of detrital sediments which contain clasts from the active Eurasian margin, the ophiolites and the autochthon. These Palaeocene to Middle Eocene series are deformed as a fold and thrust belt structural setting typical of a collision front (Fig. 6). Nevertheless the progagation in space of these structures are unknown and must be studied in more detail. Moreover the sedimentology and sequence stratigraphy of these formations must be carried out. According to our results the thin skin type deformation could have evolved as a thick skin one's reactivating the normal fault of the external part of the accreted passive margin (Fig. 6).

In Georgia and Azerbaijan the Cenozoic basins are very thick (more several thousand meters). The Adjara-Trialet one is an inverted basin (Fig. 2) It overthrusts to the north the Miocene Kura Basin molasses, but its origin and its structure remain not very well known. We expect the occurrence of thrusts reactivating normal faults of the basement basin (Eurasian basement) since Palaeocene. According to Adamia et al (1981) this basin will be a back-arc basin, mainly during Middle Eocene time consequently at the same period of time during which the collision occurred in the Lesser Caucasus. This is in contradiction and must to be investigated with collecting new stratigraphic and structural data.

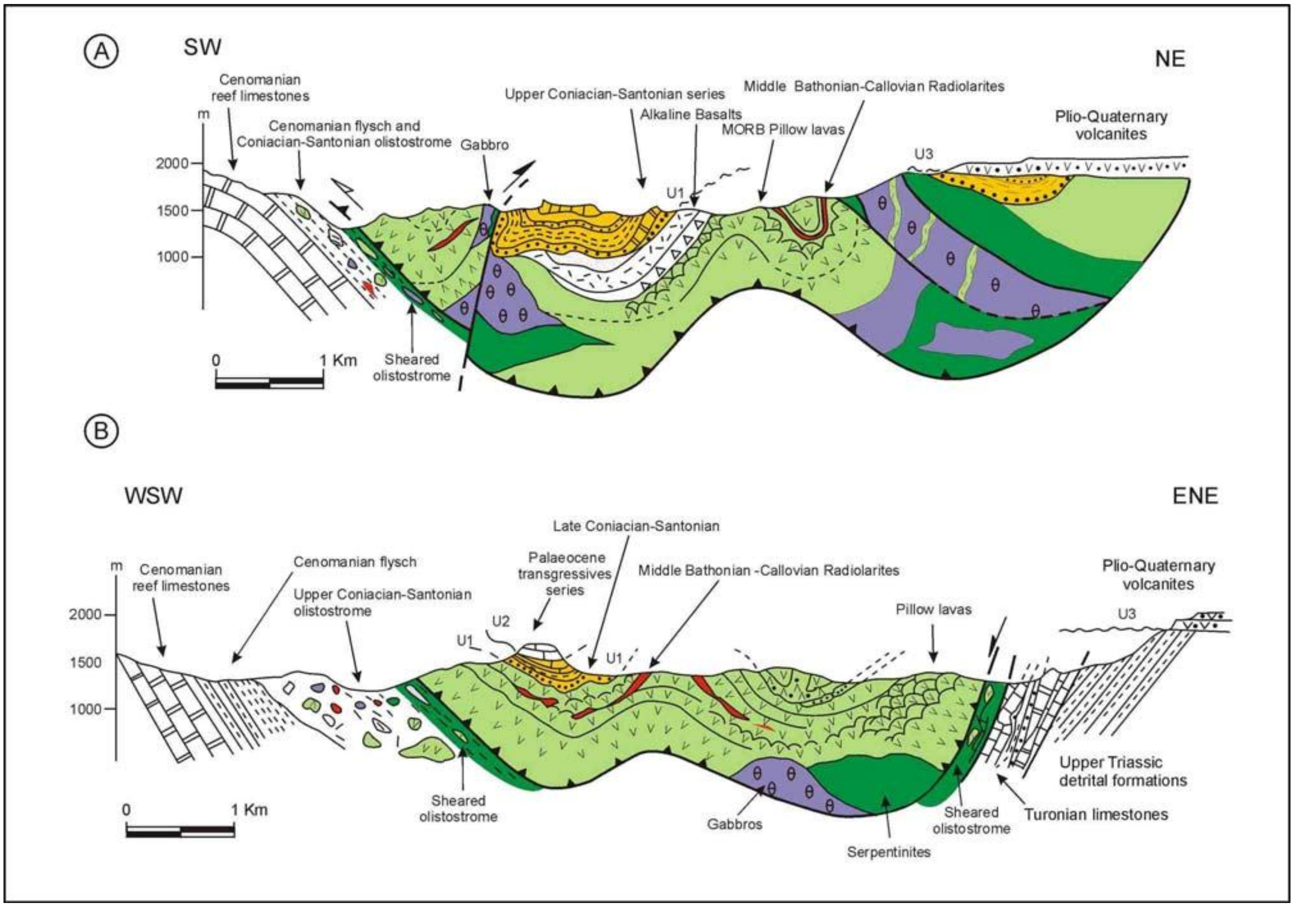

Fig. 6. Cross section of the front of the belt in hte Vedi area (Armenia), location on Fig. 2.

The thick Miocene formations of the Rioni Basin and Kura Basin (Georgia and Azerbaijan) are deformed by a recent tectonics related to the Greater Caucasus uplift (Fig. 2). The Kura and rioni Basins correspond to foreland basins in front of the Greater Caucasus mountain belt. The deep structures of the basins are not well understood particularly from the Kura plain to the Lesser Caucasus and from the Pontides to the Rioni plain.

IRG programme on this theme.

1. Within the three South Caucasus countries, and more particularly in Armenia, regional and detailed geological mapping have to be carried out from the abundant previous data and by a structural control on the field using modern methods. This approach is the first step of all high

quality geological work. These geological data must be integrated in a GIS during the next four years. The Institute of Geological Sciences in Armenia (Yerevan) has the objective in project with as final product the realisation of the geological map of Armenia. This works has to be support by the training at modern mapping methods for young local geologists *Consequently one of the priority of the IRG will be to involve the formation of young researchers from the three South Caucasus countries (Armenia, Azerbaijan and Georgia).*

2. The existing well data have to be used in order to constrain geometry of structures of the basin and of the belt. Unfortunately exploitable seismic lines do not exist for the armenian territory, however surface data (maps, structural analysis, stratigraphy, dating) and well data must allow to reconstruct more significant and pertinent deep structures of the basin and of the belt than these are commonly accepted today. Concerning data from Azerbaijan and Georgia the knowledge statement is more upgraded due to the occurrence of seismic lines and drilling areas. However all these data must be integrated in a data base (GIS type for example). The Georgian and Azerbaijan colleagues have already worked in this aim. They are in touch with local and European oil companies having acquired these types of data.
3. As mentioned above the sedimentary basins located in front of the belt (Palaeocene–Middle Eocene to Oligo-Miocene), on the suture zone (Middle to Late Eocene) and on the Eurasia (Middle to Late Eocene for Adjara-Trialet basin, Miocene to recent for Kura and Rioni basins), have not been studied with modern methods of sedimentology (facies and environment) and by methods of the sequence stratigraphy. These approaches are very fruitful for any research on hydrocarbon exploration. The reservoirs can be located within the Cenozoic detrital series overthrusted by frontal units, ophiolites or the Eurasian margin in front of the Greater Caucasus (Fig. 8). Moreover, studies on the geochemistry of the organic material have to be carried out on the autochthonous Palaeozoic formations (Devonian and Permian) which present characteristic of source rocks. *Consequently the IRG has to investigate all these type of researches by a team of specialists in these approaches having in charge to work with our South Caucasus partners.*
4. The structure of the Sevan-Akera suture zone and its relationships with the allochthonous units of the Eurasian margin in Georgia and Azerbaijan is not well known; even we have already proposed a new interpretation from the Armenian territory data (Fig. 5). This is particularly the case of the NW extension of the Lesser Caucasus with the Adjara-Trialet and Rioni basins in Georgia and Lesser Caucasus SE extension in Azerbaijan. The mountain belt has recorded three main tectonic phases at least. Consequently more detailed fieldworks have to be performed in order to constrain the surface and subsurface structures. Researchers specialized in structural analysis and tectonic (paleo-stress field reconstruction) will must work together on these topics and share information and data.

All these researches have significant coherences with exploration of hydrocarbon in the Lesser Caucasus. Consequently the IRG has to support our partners of the South Caucasian countries by developing scientific knowledge and formation of young geologists specialized in the hydrocarbon exploration in complex geological setting.

Task 3. Origin and significance of syn to post-collisional magmatism: Lithosphere-Asthenosphere interaction during the main stages of the geodynamic evolution

In the collision mountain belts following closure of Tethyan oceanic basins, the presence syn-to pot-collisional magmatism is generally not well understood. While numerous models of geodynamic evolution have been proposed to explain such magmatism, several facts remain unexplained from the available field and geochemical data, and subsequent modelling.

1. **By which geodynamic processes such a large magmatism, widespread after collision and accretion of micro-plates with Eurasia may be explained? This is the case of the Iranian and South Armenian microplates.**

The main cause for this magmatism after the accretion of the South Armenian Block is inferred to be the permanence of a subduction zone between this block and Eurasia (Adamia et al., 1981). However, we have demonstrated that suturing has occurred before this magmatism (see Figs 2-3). It is thus necessary to find another cause and document it by appropriate data to feature the source of magmatism and its timing with respect of main tectonic events. In other places of the Alpine mountain belts, main magmatic phases are ascribed to slab-break off processes (Davies and Von Blanckenburg, 1995). Furthermore, in the three Lesser Caucasus countries, this magmatism has generated some "porphyry-copper", bearing significant and exploited Copper, Molybdenum, Silver and Gold resources. Mines in Armenia, Azerbaijan and Georgia are located in magmatic complexes formed above subduction zones (with ages ranging from the Upper Jurassic to the Lower Cretaceous), or in a collisional context since the Palaeocene (see publication list of the team). It appears therefore essential to better understand the setting of this magmatism and related ore complexes.

In the Lesser Caucasus, the collision phase of the Armenian block with Eurasia started in the Palaeocene. Since this period the region experienced ongoing shortening emphasized in the Late Oligocene times by the collision of Arabia with the South Armenian Block. Crustal-scale structures witnessed by surface geology comprise a fold-and-thrust belt, as expected. However, other features are not explained well by this shortening context. In particular the presence of extensional faults and calc-alkaline magmatism are not well accounted for in such a context. It is thus important to analyse in detail the key geological data allowing the reconstruction of tectonic events of this large and complex area.

The main tectonic events recognized in our recent work are the following: (1) At the Paleocene-Eocene transition, a foreland basin is evidenced at the chain front, where are transported the erosion products of the Eurasian hanging wall. The basin also collects eroded material of the ophiolite, which was obducted on top of the South Armenian Block, and the autochthonous formations. (2) Shortening propagates from the NE to the SW, and results in the formation of folds guided by reactivated normal faults of the autochthonous basement (Fig. 6). This deformation goes on until the end of the Oligocene. However, one can notice a transgression of volcano-sedimentary formations overlain by purely volcanic sequences above the foreland basin (Figs 2 & 7). This transgression appears to start at the end of the Middle Eocene (Sosson et al. , accepted). It unconformably seals the previous set of folds of the suture zone formed during the propagation of the flexural basin. But, the structures formed during this volcanic phase have been transposed. The geological cross-sections undertaken across the suture zone (Fig. 7) show that previous NE dipping faults that developed during the emplacement of Upper Eocene volcanics were re-used as thrust faults. Consequently, what was the structural, tectonic and geodynamic context of this post-collisional basin emplaced above the suture zone? The figure 3 model proposes an explanation of asthenosphere up rise following slab break-off, but at this stage it remains a working hypothesis.

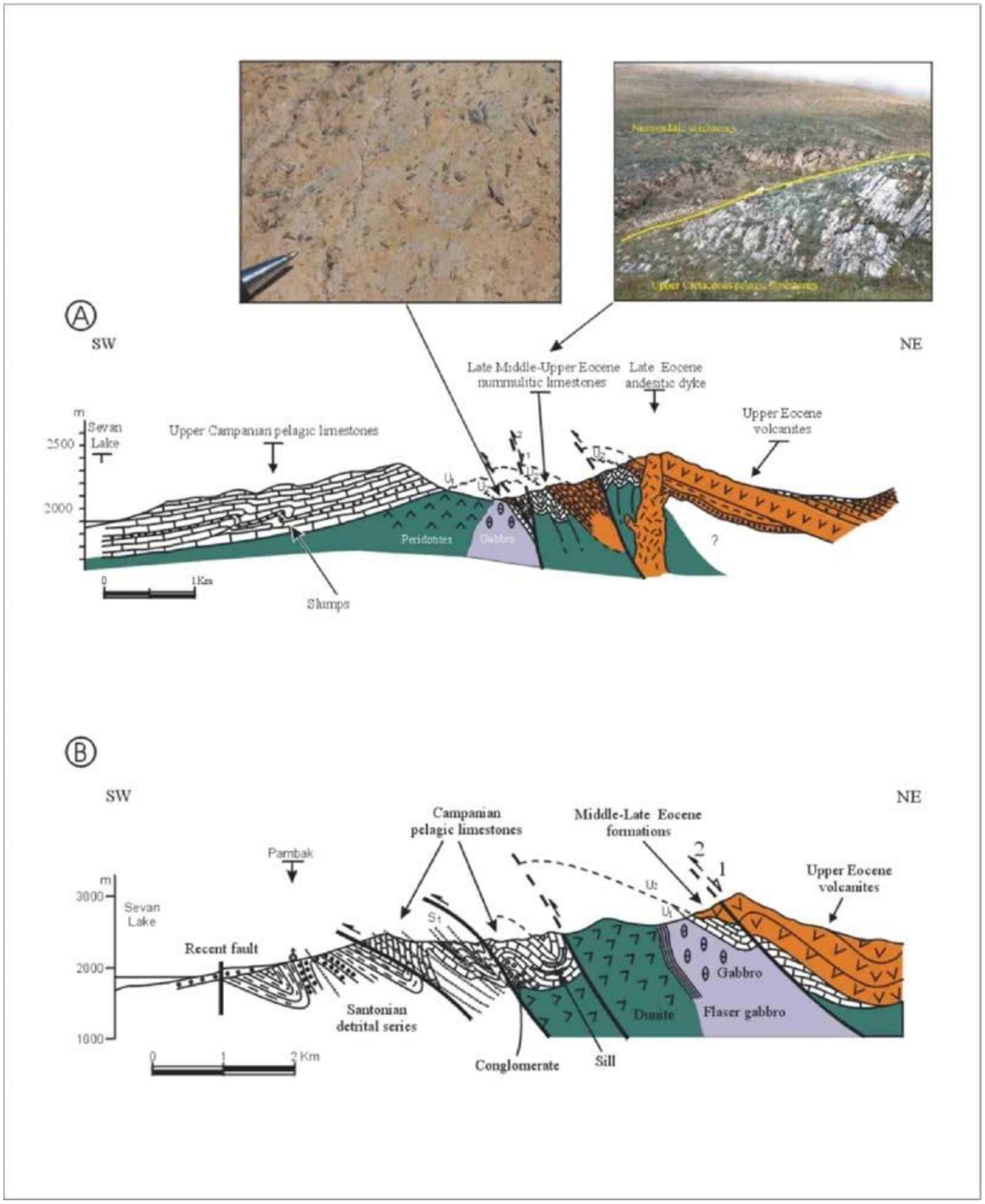

Fig.7. Cross-sections through the Sevan-Akera suture zone, location on Fig. 4. Reverses faults reactivate normal faults. On cross section A, one note the presence of the huge Middle-Late Eocene unconformity on the suture zone and the Eurasian margin.

IRG program on this theme:

- Structural analysis of the Upper Eocene volcanoclastic and volcanic series in order to reconstruct the paleo stress field (extension? as indicated by presence of normal faults reactivated as reverse one's).
- Dating of the volcanoclastics series by Nannofossils and Foraminifers (Nummulites)
- Lavas flows dating by Ar/A method
- Geochemical analysis (isotopic data) of the lava flows in order to constrain the Eocene magmatism origin

– Metallogeny on the intrusions and the volcanic series, characterization of the ore-deposits of orogenic and/or epithermal types. Integration of the geochemistry analysis, structural and lithological data in a data base (type GIS).

2. What is the cause of the Miocene-to Quaternary magmatism affecting the entire region from the chain front over Arabia to the Great Caucasus?

Some models have been proposed, of which the most recent (Faccenna et al., 2005) invoke a slab break-off process of the subducted (Arabian) Tethyan slab below the Anatolian plateau, leading to asthenosphere up rise. If the model explains the magmatism known in Anatolia, it does not account that affecting the Greater & Lesser Caucasus, and north Iranian regions.

This magmatism has generated, as stressed above, Molybdenum-Copper-Gold rich intrusions (as in the Kajaran mine of south Armenia). But the geodynamic and structural contexts of their formation are not yet understood. Further on, the outcropping of the deep and ore-rich parts of these magmatic systems appears to be controlled by a significant vertical uplift, which still awaits some quantification.

Since the Miocene, the stress field changes drastically (Avagyan et al., 2005). The main stress direction is oriented N-S, and the tectonics become transpressive, driven by the reactivation of former thrusts and strike-slip faults, and the inversion of previous normal faults (Fig. 9). This phase is also featured by an intense magmatism in the entire region from North Arabia to the Greater Caucasus, which are accompanied by a vertical uplift of the mountain belt. The question is thus posed of the role of mantle up rise in this sector, and for what reason (delamination, break-off)? Zeyen et al. (2007) results go in this direction, showing on the basis of analysis of heat flux, gravimetry and topography that there exists a significant asthenosphere up rise below the Lesser Caucasus (Fig. 8).

IRG program on this theme:

– Geochemical analysis (isotopic data) of the lava flows in order to characterize the Miocene to recent magmatism source (Crustal melting ? Lithospheric mantle melting, Asthenospheric mantle melting ?).
– Fission tracks analysis (Apatite and Zircon) and thermochronology in order to estimate the denudation rate and evaluate the uplift rate (from Miocene granites, see Fig. 2), integrate these quantitative data in the tectonic setting.
– Constrain by all these data and those of the Zeyen's model (2007) a numerical thermodynamic model (ADELI code) in order to test various hypotheses.
– Metallogeny on the Miocene intrusions and the volcanic series, characterization of the ore-deposits of orogenic type or epithermal. Integration of the geochemistry analysis, structural and lithological data in a data base (type GIS).

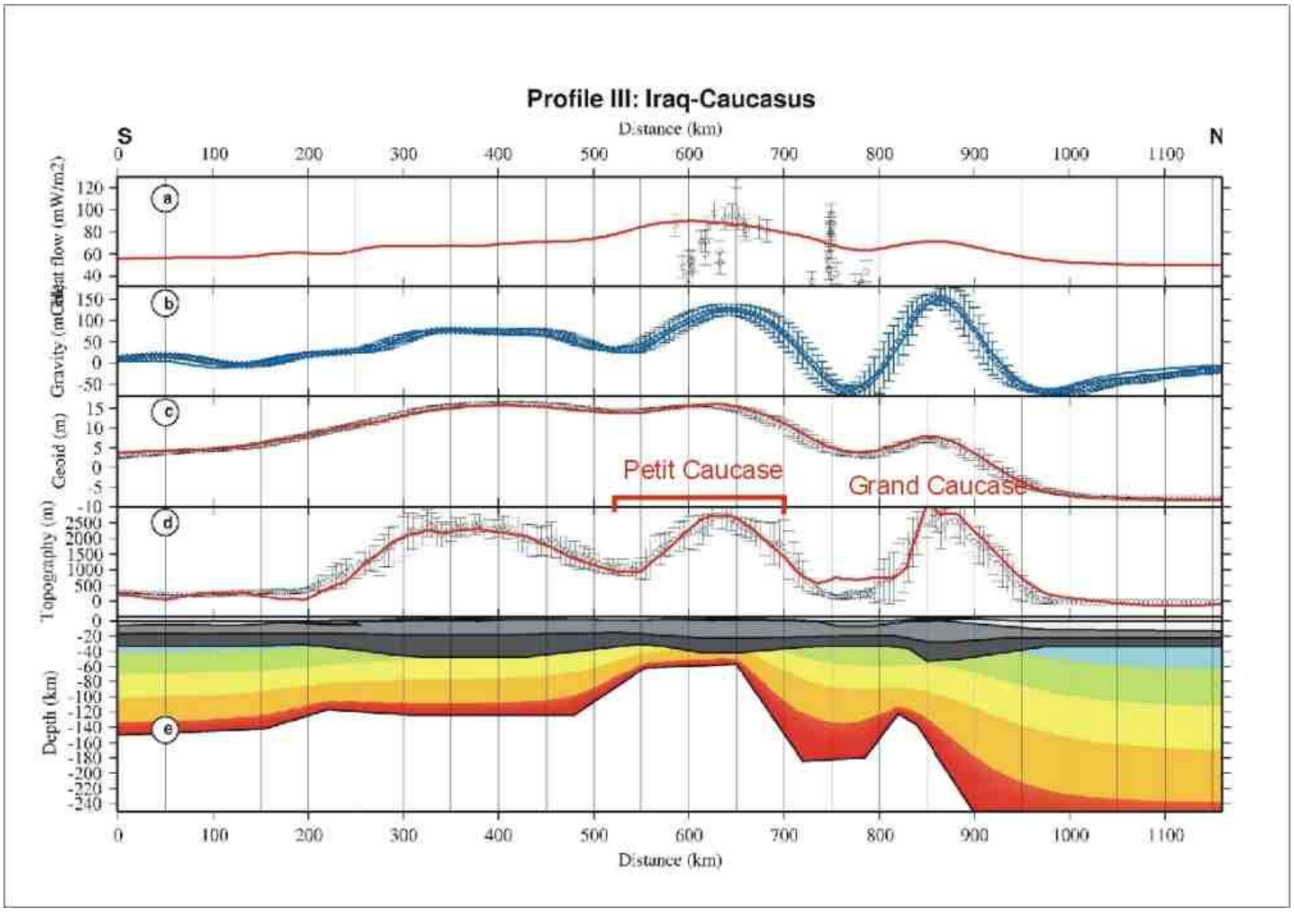

Fig. 8. N-S trending lithospheric profile from Arabian to the Greater Caucasus. One notes a 80 km thick lithosphere beneath the Lesser Caucasus (Zeyen et al., 2007).

Task 4. Localisation of the active faults: impact on basins structure and on risks.

In this still active mountain belt, with a continental climate, active structures are easily identifiable and allow by different approaches (morphology, seismotectoncs, paleoseismology, space geodesy, seismology and neotectonics) to upgrade knowledge on context geodynamics actual. Numerous works being already performed in this sense by the Armenian teams (Institute of Geological Sciences, Georisk) and by Geosciences of Montpellier (see list of publications).

Active structures in its majority are inherited structures. This is particularly well illustrated in the Sevan-Akera suture zone, north of the Lake Sevan, where the Pambak-Sevan-Sunik active fault reactivated and cuts again Cenozoic structures formed at the beginning of collision (Fig. 9). On other segments, towards the Southeast, this active fault become oblique to trusting orientation formed during the collision (Fig. 9). This obliquity could be owed to the reactivation of the normal faults in the South Armenian Block margin identifiable in the foreland of the chain (Fig. 6), case of the Garni fault for example.
This still hypothetical statement needs furthermore investigation. If it was case then the majority of active faults can located in the substratum of the South Armenian Block.

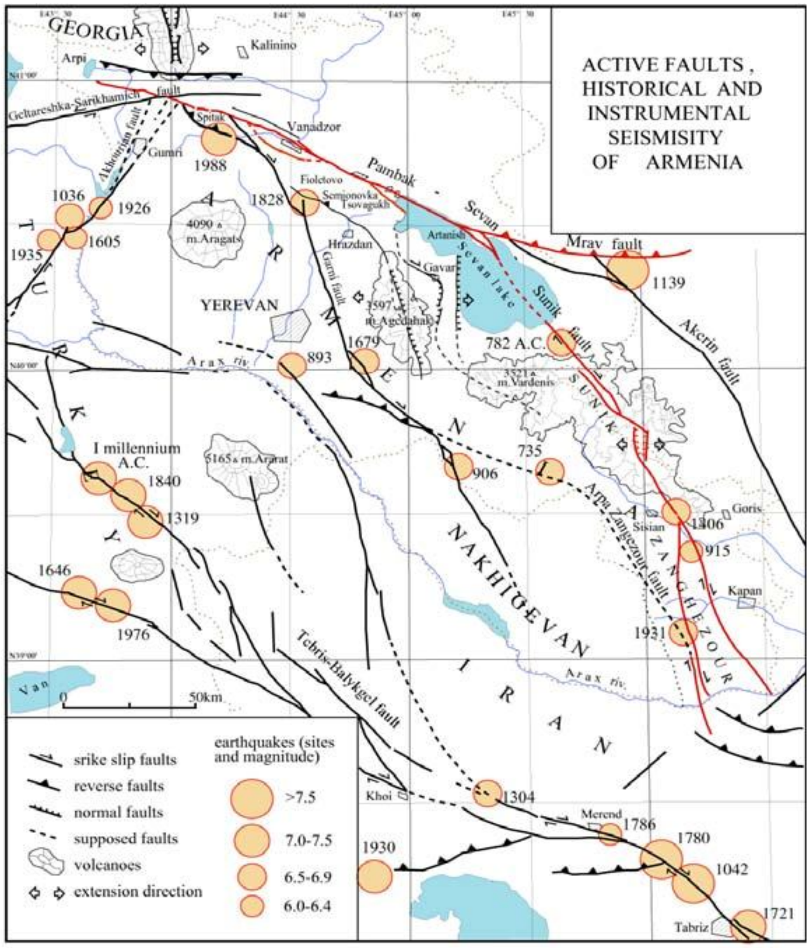

Fig. 9. Lesser Caucasus active faults map and earthquake location with their magnitudes.
In red the Pambak-Sevan-Sunik fault.

The study of relations (spatial, genetic, kinematics) between the active faults and outcropping old structures can give information about structure in the depth. The recent installation of a GPS network with 3 measurement campaigns allowed to estimate the deformation rate in the Lesser Caucasus in Armenian territory (PhD Thesis Davtyan, on 2007). Collaboration in the GPS observation of the region is started 7 years ago between Géosciences Montpellier (P. Vernant) and MIT (Reilinger and S. McClusky) in the framework of MECMO (Mediterranean / Middle East Crustal Motion Observatory). Thus the Armenian network developed in collaboration with Géosciences Montpellier integrated in a network of larger scale developed by R. Reilinger (MIT) (Fig. 10).

The quantification of actual kinematics is important to progress in the knowledge of the mechanisms of inter-continental deformation, and better understand the mechanics of the active faults. The GPS velocity of the deformation field (Fig. 10) allows to estimate the kinematics of almost rigid blocks in the region (Reilinger and al., 2006). These results must now be supplemented by paleomagnetic studies for better reconstruct the kinematics of the region.

In smaller scale the quantification of transitional elastic deformation by GPS and InSAR allows to study the mechanics of seismic cycle. The combination of the paleoseismological and geodesic studies allows the better seismic risk assessment. It is envisaged as part of a collaboration Armenia / Georgia / France to develop one denser GPS network to study phenomena linked to the seismic cluster located along Armenian-Georgian border (Fig. 10).

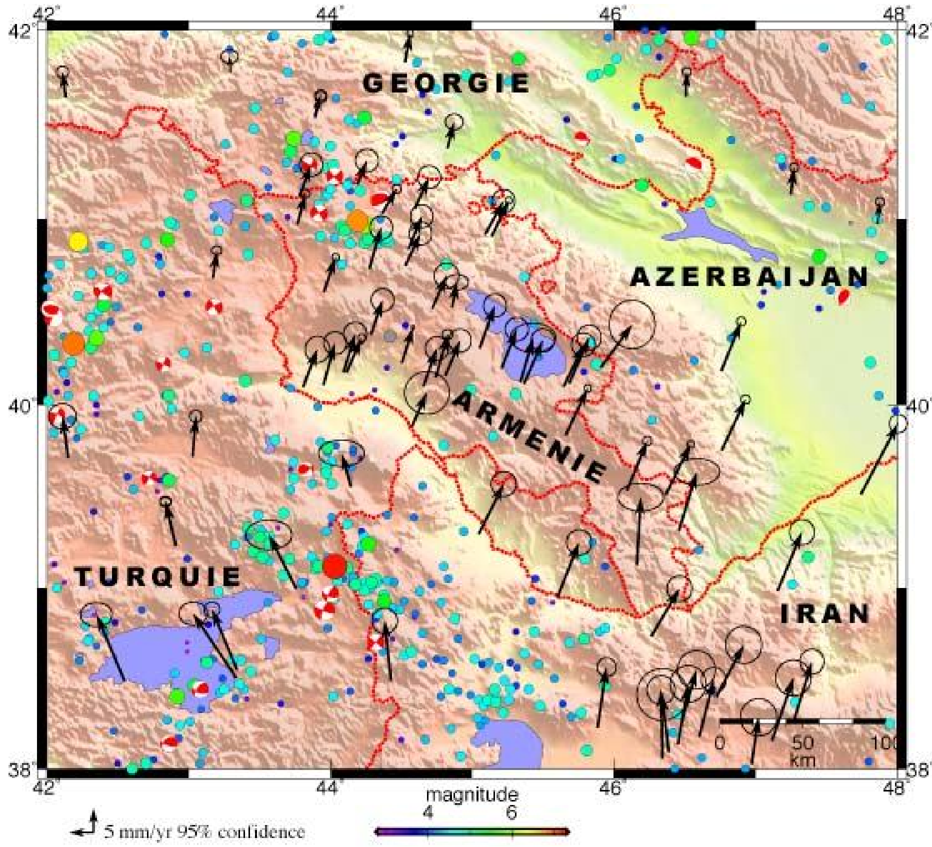

Fig. 10. GPS velocity of the deformation field in the region of Lesser Caucasus
(Reilinger and al ., 2006, Davtyan, 2007).

Impacts on risks

- Earthquakes related to the active faults are frequent in the zone of Arabo-Eurasian collision. Their direct and indirect consequences (landslides, collapses, rockfalls, liquefaction, buildings destruction due to shaking) constitute the major risk of the countries of the South Caucasus.
- The faults considered non active and partly known by the structural analysis can be reactivated (example of the Rutbar surface rupture in 1991 and of the Spitak one's in 1988) in the conditions of the actual stress field. A cross-analysis between the structural geology and seismotectonics is necessary to identify structures presenting a reactivation potential.
- The identification of seisms (location, time, magnitude) and behaviour parameters of the active faults (slip rate, time of recurrence, kinematics; Mmax) constitute the foundation of the seismic hazard knowledge and important in the seismic risk prevention in these three countries.

IRG programme on the three countries of South Caucasus:

– Mapping, (suite of ongoing work on the location of the active faults, its extension on Georgia and Azerbaijan).
– Morphological study, Realization of trenches.
– Seismotectonic, Paleoseismic Study, evaluation of slip rate.
– Paleomagnetic studies to better reconstruct the kinematics of the region.

– Mapping of risk zones.

Task 5: Paleomagnetism of dated volcanic rocks from the South Caucasus mountain belt.

Knowledge of the basic characteristics of the ancient geomagnetic field in the geological past provides valuable information about the formation and evolution of the inner solid core, mantle and outer shells of the Earth. In particular, time variation of the average, dipolar paleointensity through time is a subject of active discussion in the modern literature. The numerous volcanic episodes linked to the geodynamical processes of the Lesser Caucasus mountain belt represent a potential detailed sampling of the history of the Earth's magnetic field. Two objectives have to be studied.

Part 1 : Long-term fluctuations in intensity of the ancient Earth's magnetic field.

Paleointensity determinations obtained up to date on a worldwide scale indicate the existence of large, long-term changes of the geomagnetic dipole strength with time, highlighting a period of low dipole field (approximately a third of the present value) during most of Mesozoic time (Prévot et al., 1990; Perrin & Shcherbakov, 1997). Nevertheless, the number of absolute paleointensities available is extremely low: only about 2000 data are published. Their distribution in time is moreover extremely unequal and numerous determinations are unreliable as it is underlines by the fact that mild selection criteria based on quality eliminates already 63% of these data, in particular, almost all determinations between 4 and 60 Ma. The acquisition of new data for the Paleogene appears essential if we want to link the fluctuations of field intensity to the dynamics of Earth's core and, understand the change from the Mesozoic dipole low to the Plio-Pleistocene strong field.
In order to improve our knowledge on this subject, a cooperation between the paleomagnetic teams from Montpellier and Borock Observatory was launched. One of the expected results of this collaboration was to test the validity of Russian paleointensity data obtained in the last century. Data obtained between 1960 and 1990 by Bol'shakov and Solodovnikov, two famous Russian paleomagnetists, are crucial for the analysis of the dipole field intensity during the Phanerozoic (more than 20% of the available data). However, the lack of basic information in the original papers makes extremely difficult to assess the reliability of these determinations, leading many authors to exclude these data from their analysis. In order to test the validity of these paleointensities, a joint field work has been carried out in 2006 in northern and southern Armenia, an area previously studied by Bol'shakov and Solodovnikov (1983). From this exploratory survey, technically good results from five sites have been published (Shcherbakova et al., 2009). The Mean Virtual Dipole Moments (VDM) obtained are low – 1.7 to 5.5x 10e22 Am2 – in agreement with data published earlier. Now, spurred on by these good results, we think important to get more paleo-intensity determinations from well dated additional sites in Armenia as shown in the following map.

Part 2 : The asymmetric saw-tooth pattern of paleomagnetic intensities : An experimental check from South Georgia volcanic rocks.

An interesting pattern of geomagnetic field intensities over the last four million years was observed for the first time by valet and Meynadier (1993) in their analysis of oceanic sediments from equatorial Pacific Ocean and equatorial Indian ocean (Meynadier et al., 1994). Their record of intensities is characterized by an asymmetrical saw-tooth pattern associated with reversals of the Earth's magnetic field; a gradual slow decrease in intensity before a reversal is followed by a very rapid recovery immediately following the polarity changes. Similar observations have been repeated in several places in different oceans and seas (see e.g. for the most recent work, Huang et al, 2009). However the interpretation of the saw-toothed pattern in paleointensity is very questionned. What is in question is the ability of sediments reliably to record and preserve the intensity changes. For example, Kok and Tauxe

(1996) have shown that unremoved long term viscous remanent magnetization can explain the saw-tooth pattern and concluded that this latter is not of geomagnetic origin. On the contrary, recent numerical models of convection-driven dynamo in spherical shells are able to simulate such paleo-intensity trend (Coe et al, 2000). An independent testing of the asymmetric saw-tooth pattern is therefore required, and lava flows provide the best opportunity.

A plio-pleistocene volcanic sequence located in the southern part of Georgia and well exposed along the Paravani River, appears particularly well suited to bring insights into this controversial debate. We already carried out a detailed sampling of the lower part of the sequence (Camps et al, 1996). This sampling has been recently completed upward (Goguitchaichvili et al, 2009). Now we think important to sample the whole sequence, we estimate that the upper 300 m remain still unsampled.