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The Silurian Salinic Disturbance – newly discovered orogenic event in the northern Appalachians

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Ив. Димитров – Силурийский орогенез Салиник – новоустановленное орогеническое событие в северных отделах Аппалачских гор. Силурийские и ордовикские породы северных отделов Ню Брунсуика испытали воздействие двух региональных деформационных событий. Первая деформация связана с орогенезом Салиник (поздний уенлок – ранний лудлоу – 426–421 Ma). Он привел к образованию складок с северо-западным простиранием осевых плоскостей, а также – редкого кливажа и редких синхронных разломов. Вторая региональная деформация (Акадский орогенез) произошла в нижнем – среднем девоне (407–390 Ma). В нижнесилурийских породах Акадские деформации наложены на структуры Салиника, а в верхнесилурийских породах они представлены только одним этапом складчатости. С Акадской революцией связано образование интенсивного кливажа и многочисленных разломов. В нижнесилурийских породах наложенные складки отличаются пологим погружением и пересекаются Акадским кливажом. Тот-же кливаж проходит и через Акадские складки. Кинематика деформации Салиник не изучена, но установлено, что Акадская деформация осуществилась во время интенсивных правосдвиговых движений. Это привело к образованию разломного кливажа и к кулисному расположению Акадских складок по отношению к сильно напряженным сдвиговым зонам. Становление большей части разломов в северных отделах Аппалачских гор очевидно произошло или синхронно с Акадским складкообразованием, или непосредствено после него. С региональной точки зрения правосдвиговые сколы имели проникающий характер. С ними связано образование нечетко выявляющихся разломов, параллельных слоистости.

Abstract. In northern New Brunswick the Silurian and Ordovician rocks have been affected by two regional deformation events. The first deformation is attributed to the Salinic orogeny. It took place during the late Wenlockian – early Ludlow (426–421 Ma) and produced tectonic folds with northwest striking axial surfaces. Evidence for cleavage and faulting coeval to this event is rare. The second regional deformation took place during the lower to middle Devonian (407–390 Ma) and is know as Acadian orogeny. The Acadian deformation overprinted the Salinic structures in the lower Silurian rocks but produced single fold generation in the upper Silurian rocks. Intensive cleavage and widespread faulting are related to the Acadian revolution. The refolds in the lower Silurian rocks are steeply plunging. The refolds are overprinted by the Acadian cleavage, while the Acadian folds are dextrally transected by the same cleavage. The kinematics of the Salinic deformation is not understood but it is known that the Acadian deformation was achieved during intensive dextral shear, which resulted in transecting cleavage and an echelon arrangement of Acadian folds with respect to the high-strain shear zones. Most of the faults in the northern Appalachians appear to be synchronous or to postdate the Acadian folding. The dextral shear was penetrative on a regional scale and resulted in numerous bedding parallel faults with hidden separation.

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Key words: Silurian, Salinic, deformation, stratigraphy, folds, faults.

Introduction

Progressive accumulation of evidence indicates a complex orogenic history during the Late Ordovician and Silurian, which is neither related to Taconic nor Acadian deformation. Extensive age dating in Newfoundland has led to introduction of the Salinic Orogeny (Dunning et al., 1990); a name inspired by the earlier recognition of a late Silurian unconformity in northwestern Maine (Salinic Disturbance) by Boucot (1962). In Newfoundland the Salinic orogenic activity is known to have culminated during the late Early Silurian, because folded lower Silurian rocks are unconformably overlain by upper Silurian volcanic rocks (Dunning et al., 1990). Geochronology of metamorphic rocks in northern New Brunswick combined with sedimentological constraints has revealed a similar time span of Salinic orogenesis, which culminated during the Wenlock-Ludlow (van Staal and de Roo, 1995; Wilson et al., 2004). Silurian deformation and erosion were also recognized in Québec's eastern townships (Tremblay and Castonguay, 2002) and Gaspé (Bourque et al., 2000; Bourque et al., 2001).

So far the Salinic deformation is not recognized in Europe, although presence of erosion synchronous to the Salinic unconformity is mentioned (e.g. Erikson, 2004). This may be because Silurian deformation is missing in Europe or because of the widespread alpine reworking of the Paleozoic rocks, which obstructs detailed studies. Finally, Silurian tectonism may have evaded recognition, because of the old current of thinking according to which the Silurian is considered tectonically stable period. Significant outcrops of Silurian and Ordovician rocks are present in west Bulgaria. In order to interpret these rocks understanding of the global Silurian tectonics is required.

Stratigraphy

The Silurian and Devonian rock assemblages of northern New Brunswick and Gaspé are collectively known as the Gaspé Belt (Wilson et al., 2004). The Gaspé Belt comprises three structural zones, which from northwest to southeast are referred to as the Connecticut Valley – Gaspé Synclinorium, the Aroostook – Percé Anticlinorium, and the Chaleur Bay Synclinorium (Fig. 1, inset).

The Chaleurs Bay Synclinorium in northern New Brunswick and Gaspé contains the most complete section of Silurian formations in North America deposited in a successor trough that inherited the Yapetus Ocean. The Silurian sedimentation was constantly shallowing and culminated in terrestrial deposition and erosion during the Devonian. The paleogeography was dominated by highlands of Ordovician rocks around which alternation of limestone and conglomerate was deposited. Nowadays the Ordovician rocks are preserved as structural inliers, which share common deformation history with the Silurian cover.

The Chaleurs Bay Synclinorium mainly consists of Silurian rocks of the Chaleurs Group and to a lesser extent Lower Devonian rocks of the Dalhousie Group (Fig. 1). The lower part of the Chaleurs Group either was deposited in a trenchward migrating forearc basin or in a related accretionary slope basin, separated from the adjacent forearc basin by the Popelogan ridge (Wilson et al., 2004). Conversely, the Upper Silurian and Devonian rocks were deposited in a northwest migrating foreland basin (Bradley et al., 2000).

Two conglomerate and two calcareous formations form distinctive horizons in northern New Brunswick. The Weir Formation represents the first conglomerate level, which marks fast emergence of the Miramichi Highlands and the Elmtree Inlier above see level during the Llandovery. The reefal and basinal limestone of the La Vieille Formation deposited during the Upper Llandovery-lower Wenlock marks slow emergence and overall tectonic stabilization, which was interrupted by renewed tectonic uplift, erosion and conglomerate deposition during the second half of the Wenlockian.

During the latest Wenlockian the Salinic mountain building and folding (F_1) affected all rocks of the Silurian basin and the Ordovician inliers. The polygenic boulder conglomerates of the South Sharlo Formation and other equivalent facieses of late Wenlockian age were sinkinematic to the Salinic folding. Early Ludlovian clastic facies of the Simpsons Field Formation overprinted the F_1 folds as it marks end of the Salinic deformation. The Simpson Field Formation was overlain by reefal and basinal limestone facies of the LaPlante Formation, which marks tectonic stabilization and gradual emergence during the Pridolian and early Devonian.

In late-early Devonian the Acadian orogeny began and continued with interruptions until the Carboniferous. The main Acadian folding (F_2) in the study area appear to be Emsian but it is proven by facies changes and age of plutonism that on a larger scale the deformation was time transgressive.

Along the margins of the Ordovician inliers the rock fragments in the clastic formations record the Salinic and Acadian exhumations. Both the lower Silurian (La Vieille Formation) and the upper Silurian (LaPlante Formation) limestone horizons have been deeply eroded. The La Vieille Formation has been eroded during the late Wenlockian Salinic uplift and during various pulses of Devonian to Pennsylvanian erosion that followed the Acadian orogenesis. La Plante reefal rocks were affected by deeper erosion, because they were deposited higher in the stratigraphic sequence and thus were first affected by Devonian and Carboniferous denudation.

Isotopic dating of metamorphic minerals from Ordovician rocks confirm the chronology inferred from the stratigraphy of the overlying Silurian rocks. The beginning of the Salinic metamorphic recrys-

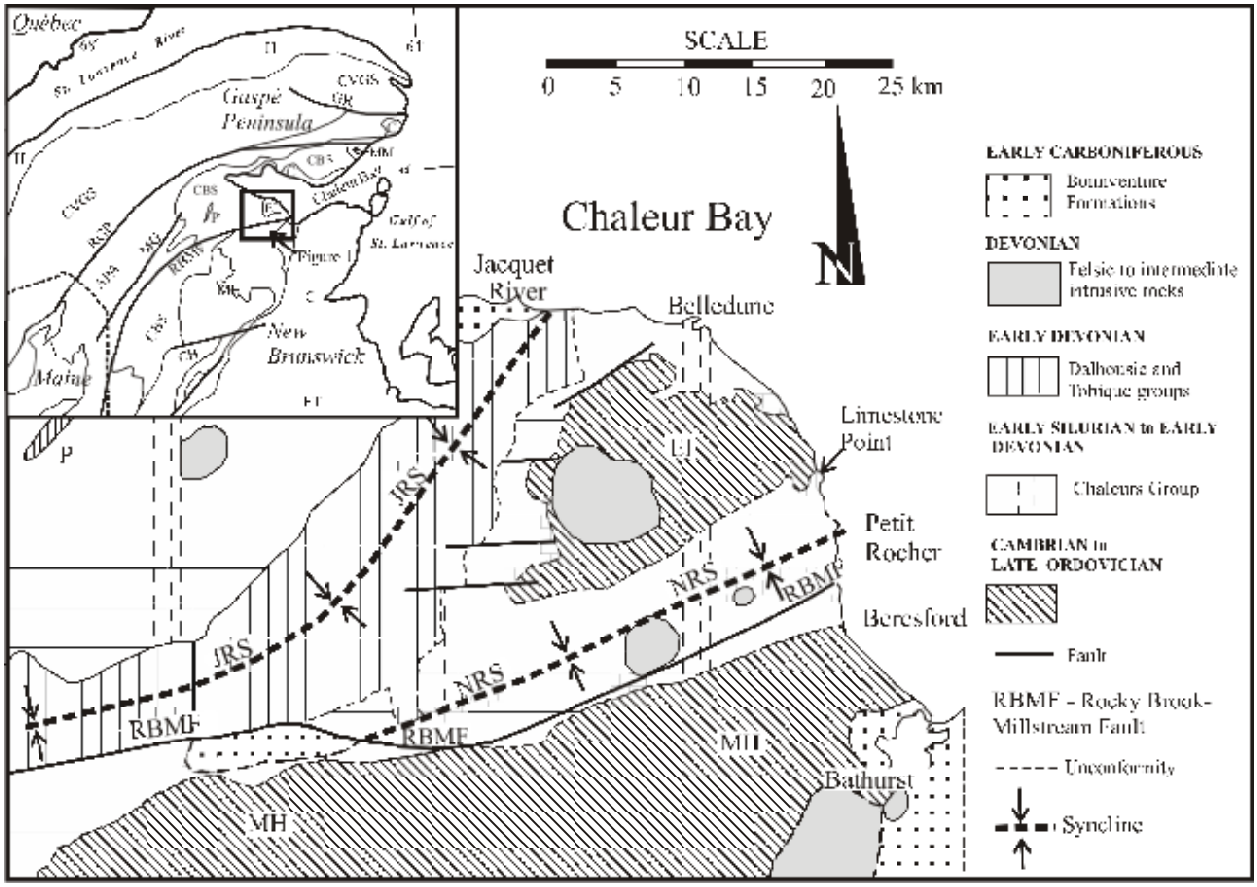

Fig. 1. Location map of the study area. The inset shows major tectono-stratigraphic subdivisions in the Appalachians of northern New Brunswick and Gaspé Peninsula. Abbreviations as follows: APA – Aroostook – Percé Anticlinorium; C – Carboniferous; CB – Catamaran Brook Fault; CBS – Chaleur Bay Synclinorium; CVGS – Connecticut Valley – Gaspé Synclinorium; EI – Elmtree Inlier; FT – Fredericton trough; H – Humber Zone; JRS – Jacquet River Syncline; GR – Grande Riviure Fault; MG – McKenzie Gulch Fault; MM – Maquerau Mictow Inlier; MH – Miramichi Highlands; NRS – Nigadoo River Syncline; P – Popelogan Inlier; RBMF – Rocky Brook – Millstream Fault; RGP – Restigouche – Grand Pabos Fault

tallization is constrained by $^{40}Ar/^{39}Ar$ ages of metamorphic phengites and crossites, which indicate Ashgillian – Llandoverian (442–430 Ma) ages (van Staal et al., 1990; van Staal et al., 2003). Second stage of recrystallization is constrained between 428 and 400 Ma based upon $^{40}Ar/^{39}Ar$ cooling ages of metamorphic muscovite. The main stage of Salinic folding, constrained by dating of coeval foliation, took place between 430 and 418 Ma but was most likely diachronous (van Staal et al., 2003).

The post-Salinic exhumation of the deeply buried Ordovician sediments must be more or less coeval with the Ludlovian clastic formations in the cover rocks (422–418 Ma) as it was probably finished by 418 Ma (van Staal and de Roo, 1995).

Folding

Studies of coastal outcrops demonstrated that the lower and upper Silurian rocks have different structural geometry. The rocks stratigraphically overlaying the Ludlovian conglomerates and the conglomerates themselves are affected by shallowly plunging F_2 (Acadian) folds. The rocks underlying these conglomerates are affected by steeply plunging F_1–F_2 refolds. The F_2 folds have smaller amplitude and half-wavelength than the F_1 (Salinic) folds. For this reason, closures of F_2 are much more frequently encountered and the limbs of F_2 are easier to trace, which in conjunction with poor exposure nearly completely masked the existence of F_1. For these reason the strike of the lower Silurian formations was previously interpreted as east – west (F_2 – controlled), while in reality it is northwest-southeast or north-south (F_1 – controlled).

While the kinematic conditions during the F_1 folding are not known the formation of the F_2 folds very likely involved substantial simple shear. Penetrative cleavage (S_2) accompanied the F_2 folds. This cleavage is more northerly striking than the axial planes of the F_2 folds, and thus suggests for counterclockwise transection of the folds, which is consistent with dextral simple shear. Using the orientation of the S_2 the main shear direction can be found and some folds can be restored, so that the pre-F_2 strike of the

lower Silurian beds can be inferred. The restoration indicated that the F_1 axial surfaces were northwesterly striking prior to F_2. Locally, F_1 with north or northwest striking axial surfaces are preserved in coastal exposures, which confirms the above conclusion.

Geometrical and stratigraphic analysis of Silurian rocks allows construction of a conceptual model of deformation, which includes the following stages:

1) D_1 (Salinic deformation) imposed on sub-horizontal or openly folded strata, which produced moderately plunging F_1 folds with northwest trending axial planes (Fig. 2A);

2) Erosion and deposition of upper Silurian and lower Devonian rocks that overly F_1 (Fig. 2B, C);

3) D_2 (Acadian deformation) that refolded the F_1 folds in steeply plunging F_1–F_2 refolds, folded the Salinic unconformity and produced shallowly plunging F_2 in the upper Silurian and Devonian beds (Fig. 2D, E, F).

Faulting

In northern New Brunswick are recognized two lineament sets: a set striking in the range 45–90° and a set striking in the range 320–360°. Both sets are related to dextral strike-slip faults. The F_2 folds appear to have been formed by fault-related wrenching, so nearly simultaneous folding and faulting during the Acadian deformation in the Emsian – Eifelian (387–409 Ma) must have taken place.

In general most of the faults are considered Acadian or postdating the Acadian event. The age of the faults is determined by overprinting relationships such as: faults postdating (displacing) S_2 cleavage (Dimitrov et al., 2004; Dimitrov and McCutcheon, 2005 and 2007); large faults that offset F_2 folds (Wilson et al., 2004; van Staal et al., 2003); fault surfaces overprinted by flat-laying Carboniferous red beds; and, normal faults offsetting Carboniferous beds.

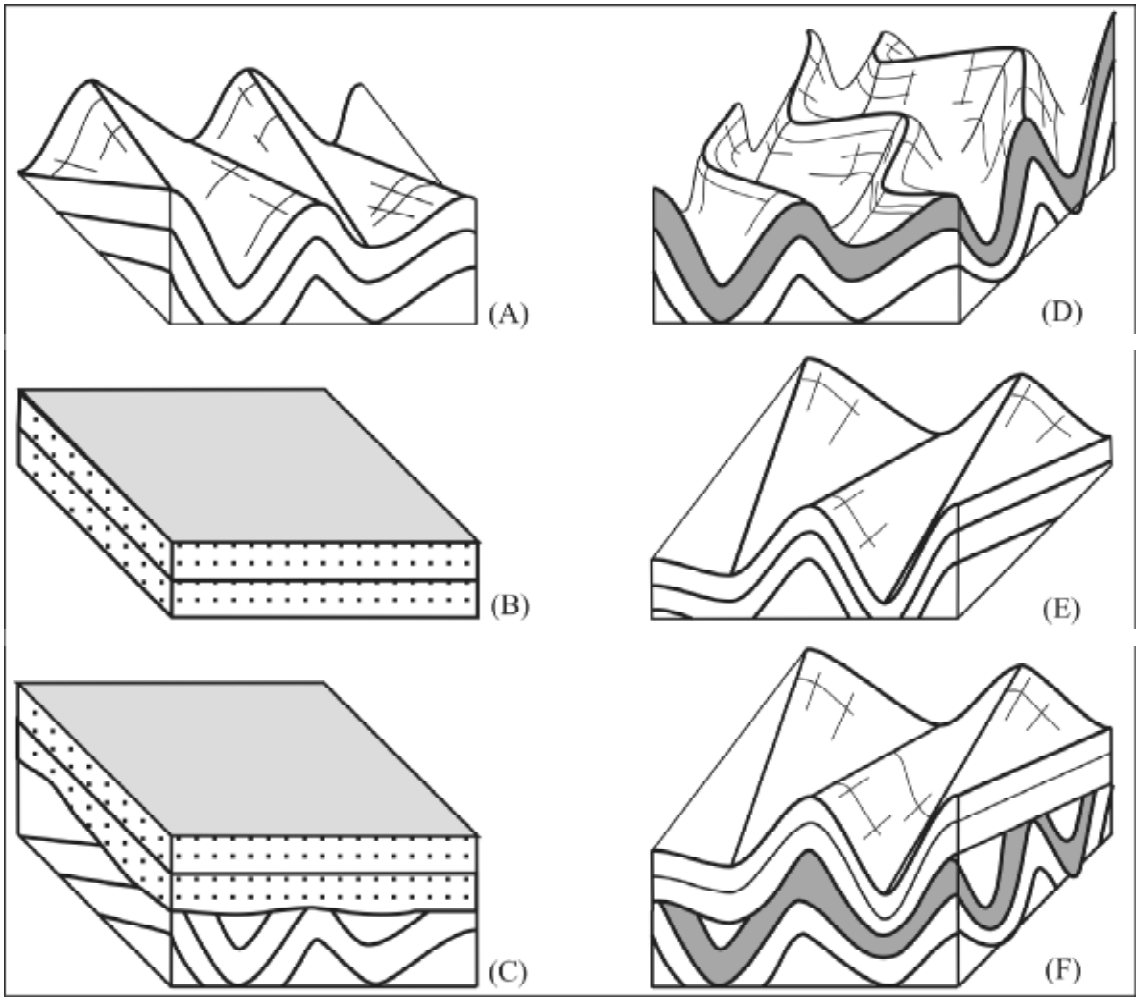

Fig. 2. Structural geological history of the Silurian rocks in northern New Brunswick. (A) F_1 folds with northwest striking axial surfaces that predated the Salinic unconformity. (B) Salinic erosion and deposition of upper Silurian and lower Devonian rocks. (C) Combined block diagram of eroded F_1 folds covered by undeformed upper Silurian and lower Devonian rocks. (D) F_2 folds overprinting lower Silurian strata. (E) F_2 folds in the upper Silurian and lower Devonian rocks. (F) Block diagram of F_2-folded upper Silurian rocks that overly F_1–F_2 refolds in the lower Silurian strata

Only small extensional normal faults affected the Carboniferous sediments. Reliable evidence for Mesozoic faults has not been found. Regarding possible early to middle Silurian faults, related to the Salinic orogeni, it can only be noted, that if such faults existed they would have been folded by F_2 and displaced by bedding – parallel shear and by larger Acadian and post Acadian shear surfaces. Only Salinic faults that had favorable orientation would have been preserved as reactivated structures. It is however difficult to date the earliest activity along the faults.

Discussion and conclusions

The Salinic unconformity poses a stratigraphic puzzle. It appears that in the northern Appalachians most significant uplift was in the second part of the Wenlockian, when the La Vieille Formation was eroded and coarse polygenic conglomerates of Ludlovian age were deposited. The Ludlovian conglomerates comprise well washed mature clastic rocks, which appear to have been reworked and redeposited in shallow marine environment. Because the conglomerates postdate both the major uplift and the F_1 folding there is not evidence for regressive deposition of conglomerates. On the contrary the significant thickness of the conglomerates can very well be product of transgressive environment (ravinement) during the Ludlovian, when the sea grinded reprocessed and redeposited previously formed alluvial gravel. This conclusion contradicts previous works (e.g. Bourque et al. 2000 and 2001) which postulate that the Salinic event is related to sea regression. Curiously enough, the Wenlock-Ludlow boundary in Gotland, Sweden, where sedimentation analogous to that of the Chaleurs Group took place, was interpreted as a ravinement surface (e.g. Erikson 2004).

On the territory of Bulgaria and Turkey the lower Paleozoic paleogeography and tectonic history are not well understood (e.g. Yanev et al. 2006). Review of the regional stratigraphical, sedimentological and paleonthological literature indicates that erosion coeval to the Salinic event can not be excluded, however evidence for folding are not available. Because the structural geological understanding of Bulgaria is affected by tectonic models focused primarily on the alpine events and the Paleozoic deformations are generally neglected it is not improbable that Salinic folds are present in Bulgaria and adjacent Turkey, where lower Silurian and Ordovician rocks outcrop.

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References

Boucot, A. J. 1962. Appalachian Siluro-Devonian. – In: Coe, K. (ed.). *Some aspects of the Variscan fold belt*. Manchester, England, Manchester University Press; 155–163.

Bourque, P.-A., Kirkwood, D., Malo, M. 2001. Stratigraphy, tectono-sedimentary evolution and paleogeography of the post-Taconian-pre-Carboniferous Gaspé Belt: an overview. – *Bulletin of Canadian Petroleum Geology*, 49; 186–201.

Bourque, P. A., Malo, M., Kirkwood, D. 2000. Paleogeography and tectono-sedimentary history at the margin of Laurentia during Silurian to earliest Devonian Time. – The Gaspé Belt, Québec. — *Geological Society of America Bulleti*n, 112; 4–20.

Bradley, D. C., Tucker, R. D., Lux, D. R., Harris, A. G., McGregor, D. C. 2000. Migration of the Acadian orogen and foreland basin across the northern Appalachians of Maine and adjacent areas. – *U. S. Geological Survey*, *Professional Paper*; 1624.

Dimitrov, I., McCutcheon, S. R. 2007. Stratigraphic and Structural Constraints on Limestone Exploration: A Case Study from Northern New Brunswick, Canada. – *Exploration and Mining Geology*, 16; 25–36.

Dimitrov, I., McCutcheon, S. R. 2005. Geotechnical implications of bedrock characteristics in the Belledune area, northern New Brunswick. – In: Martin, G. L. (ed.). *Geological Investigations in New Brunswick for 2004: New Brunswick Department of Natural Resources; Minerals, Policy and Planning Division*, Mineral Resource Report 2005–1; 23–44.

Dimitrov, I., McCutcheon, S. R., Williams P. F. 2004. Stratigraphic and structural observations in Silurian rocks between Pointe Rochette and the Southeast Upsalquitch River, northern New Brunswick: A progress report. – In: Martin, G. L. (ed.). *Geological Investigations in New Brunswick for 2003: New Brunswick Department of Natural Resources; Minerals, Policy and Planning Division*, Mineral Resource Report 2004–4; 41–74.

Dunning, G. R., O'Brien, S. J., Colman-Sadd, S. P., Blackwood, R. F., Dickson, W. L., O'Neill, P. P., Krogh, T. E. 1990. Silurian orogeny in the Newfoundland Appalachians. – *Journal of Geology*, 98; 895–913.

Eriksson, M. J. 2004. Formation and significance of a middle Silurian ravinement surface on Gotland, Sweden. – *Sedimentary Geology*, 170; 163–175.

Tremblay, A., Castonguay, S. 2002. Structural evolution of the Laurentian margin revisited (southern Quebec Appalachians): Implications for the Salinian orogeny and successor basins. – *Geology*, 30; 79–82.

Wilson, R. A., Burden, E. T., Bertrand, R., Asselin, E., McCracken, A. D. 2004. Stratigraphy and tectono-sedimentary evolution of the Late Ordovician to Middle Devonian Gaspé Belt in northern New Brunswick: evidence from the Restigouche area. – *Canadian Journal of Earth Sciences*, 41; 527–551.

van Staal, C. R., Ravenhurst, C. E., Winchester, J. A., Roddick, J. C., Langton, J. P. 1990. Evidence for a post-Taconic blueschist suture in northern New Brunswick, Canada. – *Geology*, 18; 1073–1077.

van Staal, C. R., de Roo, J. A. 1995. Mid-Paleozoic tectonic evolution of the Appalachian Central Mobile Belt in northern New Brunswick, Canada: collision, extensional collapse and dextral transpression. – In: Hibbard et al. (eds.). *Current perspectives in the Appalachian–Caledonian Orogen*. Geological Association of Canada, Special Paper 41; 367–389.

van Staal, C. R., Wilson, R. A., Fyffe, L. R., Langton, J. P., McCutcheon, S. R., Rogers, N., McNicoll, V., Ravenhurst, C. E. 2003. Geology and tectonic history of the Bathurst Supergroup, Bathurst Mining Camp, and its relationships to coeval rocks in southwestern New Brunswick and adjacent Maine – a synthesis. – In: Goodfellow, W. D. et al. (eds.). *Massive sulfide deposits of the Bathurst Mining Camp, New Brunswick, and northern Maine*. Economic Geology Monograph 11; 37–60.

Yanev, S., Göncüoglu, M. C., Gedic, I., Lakova, I., Boncheva, I., Sachanski, V., Okuyucu, C., Özgül, N., Timur, E., Maliakov, Y., Saydam, G. 2006. Stratigraphy, correlations and palaeogeography of Palaeozoic terranes of Bulgaria and NW Turkey: a review of recent data. – In: Robertson, A. H. F. & Mountrakis, D. (eds.). *Tectonic Development of the Eastern Mediterranean Region*. Geological Society, London, Special Publications, 260; 51–67.

Резюме. Ив. Димитров – Силурското салинно смущение – новооткрито орогенно събитие в северните Апалачи. В северен Нови Брунзуик силурските и ордовишките скали са повлияни от две регионални деформационни събития. Първата деформация е свързана със Салинната орогенеза. Тя е проявена в интервала късен уенлок – ранен лудлоу (426–421 Мг) и е формирала тектонски гънки със северозападни посоки на осовите повърхнини. Указанията за кливаж и разломяване, синхронни с тази орогенеза, са редки. Втората регионална деформация през долния до среден девон (407–390 Мг) е позната под името Акадска орогенеза. Акадската деформация е преработила салинните структури в долно силурските скали, но е проявена само с една гънкова генерация в горно силурските скали и девонските скали. Салинното гънкообразуване е съпроводено от ерозионно събитие известно в литературата като салинно смущение (Salinic Disturbance) или салинно несъгласие. Салинното несъгласие се изразява в ерозия през горната част на уенлок и отлагане на дебели конгломератни формации през лудлоу. До настоящия момент се счита, че лудловските конгломерати маркират регионално тектонско издигане в северните Апалачи. Тоест те са считани са регресивни образования. В резултат на последните изследвания бяха събрани данни чрез които горното твърдение може да са оспори. Новите данни сочат, че регресивната част на цикъла е била през уенлока е не през лудлоу. Лудловските конгломерати имат характер на трансгресивни отложения формирани чрез настъпване на морето и преработка на вече формирани през предшестващата регресивна фаза кластични скали. Така се стига до схващането че през лудлоу е проявена ерозия в трансгресивна обстановка (transgressive ravinement). Интензивен кливаж и разломяване са свързани с акадската орогенеза. Пренагънатите гънки в долно силурските скали са със стръмни наклони на осите. Акадския кливаж е наложен върху пренагънатите гънки, но пресича систематично, обратно на часовниковата стрелка акадските гънки. Кинематиката на салинната деформация не е изяснена, но за акадската деформация се знае, че е постигната в обстановка на регионално дясно отседно срязване, което е и причина за пресичащия синхронен кливаж и за ешелонна подредба на акадските гънки, които са формирани чрез флексурно плъзгане. Повечето разломи в северните Апалачи са синхронни или по-късни от акадското нагъване. Дясно отседното срязване е било проникващо в регионален мащаб и е съпътствано от многобройни паралелни на напластяването срязвания със скрито преместване. Нагънатите и метаморфозирани долно палеозойски скали са покрити от субхоризонтални долно карбонски пластове. Алеганската орогенеза, която е аналог на вариската орогенеза в Европа не е проявена в северните Апалачи.