

Aulacogens, the Donets Basin (eastern Ukraine, southwestern Russia), and the new classification of rifts: towards a proper terminology

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Abstract. Some intra-cratonic basins are traditionally called “aulacogens”. This term has persisted in the geoscience literature since its invention by Soviet geologists in the mid-20th century before the triumph of the plate tectonics, but its meaning has evolved. Attempts to change its meaning from descriptive to genetic have led to a broad spectrum of opinions on the definition of aulacogens. Some specialists related them to continental rifts, while others have restricted aulacogens to the only particular rift systems or peculiar stages in the evolution of young cratons. The Donets Basin is a typical aulacogen stretching across the southern margin of the East European Craton. A brief review of present knowledge of this basin shows that its nature is rather incompatible with the present understanding of aulacogens. Instead, the new classification of rifts offers a more precise terminology for its exact characteristics. It is suggested that the term “aulacogen” should only be restricted to those basins for which it has been applied historically.

Key words: aulacogen, continental rift, craton, tectonic terminology, Donets Basin.

Апстракт. Неки интракратонски басени су традиционално називани “аулакогени”. Овај термин, прихваћен у геолошкој литератури, увели су совјетски геолози средином двадесетог века, пре тријумфа тектонике плоча. Пукушаји да се измени његов генетски значај водили су до широког спектра мишљења о дефиницији аулакогена. Неки аутори доводе га у везу са континенталним рифтовима, други су ограничавали аулакоген на један део рифтних система или на одређене стадијуме у еволуцији млађих кратона. Доњецки басен је типичан аулакоген који се пружа дуж јужног обода источноевропског кратона. Кратак преглед досадашњих сазнања о овом басену показују да његова природа није усаглашена са досадашњим схватањем аулакогена. Нова класификација рифтова даје прецизнију терминологију за његове одређене карактеристике. Предложено је да термин “аулакоген” буде прихваћен само за оне басене за које су и раније били примењивани.

Кључне речи: аулакоген, континентални рифт, кратон, тектонска терминологија, Доњетски басен.

Introduction

The term “aulacogen” was coined by the famous Russian geologist N.S. SHATSKIJ and his followers in the midst of the 20th century (KOSYGIN & PARFJONOV 1970; PAFENGOL’TS 1978). It has since been used by researchers outside the ex-USSR and Russia (e.g., BURKE 1977; PERRY & PIGOTT 1983; HAMES *et al.* 1998). Although the number of publications mentioning aulacogens has not decreased until now (Fig. 1), the validity of this term has been questioned by some specialists in tectonics. For instance, according to the

textbook by FRISCH *et al.* (2011), “aulacogen” is a failed term to be replaced by “graben structure”. It should be also noted that many papers for international readership that employ this term have been written by Russian and Chinese authors.

In this brief note, I attempt to discuss whether “aulacogen” is a proper term to use within the context of modern tectonics. For this purpose, 1) its original and present meanings are examined and compared, and 2) the alternative usage of a new classification of rift structures (MERLE 2011) to describe typical aulacogens (like the Donets Basin in Eastern Europe) is considered.

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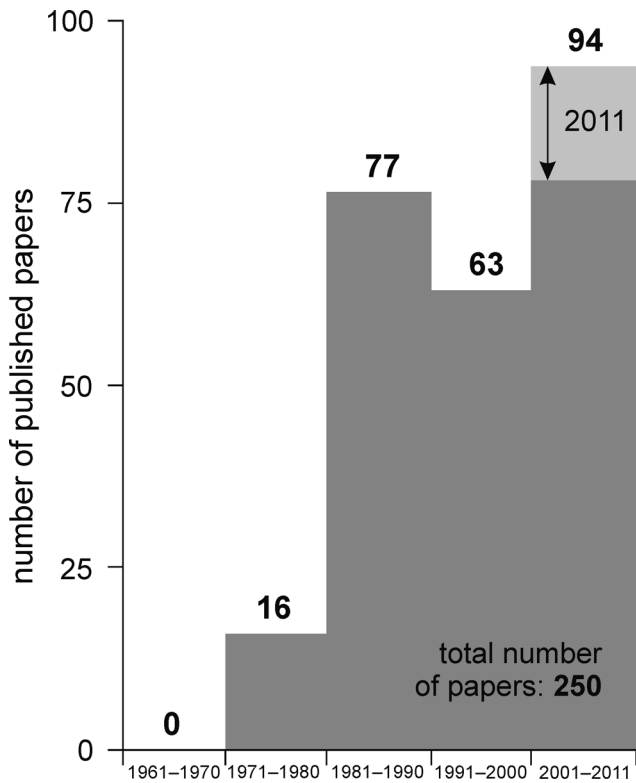


Fig. 1. Changes in the number of papers available for the international readership (based on a search of titles, abstracts, and key words in the bibliographical database scopus.com; accessed on April 9, 2012). The number of papers is indicated by columns; 16 papers were published in 2011.

What does the term “aulacogen” mean?

The term “aulacogen” was introduced by the Soviet geologist N.S. SHATSKIJ in 1964 (KOSYGIN & PARFJONOV 1970; PAFFENGOL’TS 1978). It originally meant nothing more than “a trench-like complex structure between similar zones of the platform” (KOSYGIN & PARFJONOV 1970, p. 148). Soviet geologists also emphasized thick, often folded, sedimentary cover (measured by thousands of meters) of aulacogens and controls of major faults on these basins (KOSYGIN & PARFJONOV 1970; PAFFENGOL’TS 1978). Several types of aulacogens were distinguished (e.g., KOSYGIN 1969). KOSYGIN (1969) pointed out that the original meaning of the term had already changed a few years after it was coined, and presented a broad spectrum aulacogen definitions (see also KOSYGIN & PARFJONOV 1970; PAFFENGOL’TS 1978). Interestingly, formation of aulacogens has been often attributed to a particular stage in the evolution of cratons, when young platforms experienced destructive deformations (KOSYGIN 1969; LAZ’KO 1975; POTAPOV, 1996). The East European Craton (= Russian Platform), which has been identified by Soviet geologists as an ideal object for cratonic studies, exhibited the formation of several

aulacogens during the so-called Riphean (Meso- and Neoproterozoic – see RUBAN 2009 for more details), when this craton began to evolve into a “stable” tectonic block (LEJTES *et al.* 1970; BELOUSOV 1978; VALEEV 1978; POTAPOV 1996). This interpretation appeared so obvious that even elementary textbooks in general geology tended to relate the majority of aulacogens to the late Proterozoic evolution of young cratons (e.g., KORONOVSKIJ & JAKUSHOVA 1991).

It is important to note that ideas about aulacogens appeared before the wide acceptance of the plate tectonics as a universal tectonic theory (this is especially true for the Soviet geoscience community of 1960–70s). Aulacogens were treated in terms of fixism (or, more properly, the geosyncline concept) during the 1960s and the 1970s, when crucial information about them was accumulated (KOSYGIN & PARFJONOV 1970; PAFFENGOL’TS 1978). When the theory of plate tectonics became accepted and the attention of Soviet geologists turned to extensional structures (MILANOVSKIJ 1976), the term “aulacogen” started to become related to “continental rift” and “graben”. However, some specialists expressed caution about a mix of these terms (BELOUSOV 1978). Moreover, it appears that the original definition of aulacogens (see above) does not require the formation of these structures within continental rifts (sometimes, compressed and folded after the main deposition phase), but also allows also their formation via large-scale epeirogenic deformation of cratons (often characterized in terms of dynamic topography). Nevertheless, continental rifting seems to be the most plausible explanation for the majority of aulacogens. Decades after the first definition of the term, the aulacogen stage in the evolution of young platforms was described in terms of continental rift development and the onset of extension (e.g., NIKISHIN *et al.* 1996). Thus, although the discussed term was originally only descriptive, it has “gained” a genetic sense as the tectonic knowledge of the geoscience community advanced.

The body of Soviet/Russian literature on aulacogens is huge, but what about the international publications? Below, I give some examples from books published recently. BOGGS (2006) provides several opinions on the nature of aulacogens. He notes, for instance, that these might have been failed rifts, later re-activated under a compressional regime. Following ŞENGÖR (1995), he also mentions the possible role of strike-slip displacements and tectonic block rotations in the origin of these structures. BOGGS (2006) also emphasizes the thick sedimentary cover of aulacogens and their occurrence at high angles relative to the continental margin. Does this mean that aulacogens can occur only in the peripheral parts of cratons?! This author also lists (as examples) aulacogens of a very different age (including late Paleozoic and Cretaceous structures). Reviewing knowledge of the intra-continental sedimentary basins, BAYER *et al.* (2008) note

that aulacogens are old inverted stuck rifts. FRISCH *et al.* (2011) reject the validity of the term “aulacogen”, which, in their opinion, is a graben structure with thick sedimentary cover. It should be noted that these authors refer to a rather broad understanding of grabens. In his recent monumental review, INGERSOLL (2012) treats aulacogens as fossil rifts evolved as a third arm in three-rift systems; according to this author, aulacogens are continental rifts that did not become oceans and were later compressed. Looking at recent research papers published in international journals (e.g., AITKEN & BETTS 2009; DICKINSON *et al.* 2010; TEIXEIRA *et al.* 2010; DUAN & DUAN 2011; JIN *et al.* 2011), it is easy to realize that the term “aulacogen” refers to basins related to continental extension and/or supercontinental break-up, and many of these basins are late Precambrian in age. It also appears (but this is a mere impression) that the term “aulacogen” is used historically for particular tectonic structures in some (if not many) cases.

The authors of the non-Soviet/Russian publications considered above tend to employ the term “aulacogen” with certain differences, and they always do so within the context of plate tectonics. This is far from the original understanding of aulacogens in the Soviet geoscience literature before the 1980s (see above), when this term was used within the geosyncline conceptual frame. Interestingly, none of the books or book chapters mentioned above (BOGGS 2006; BAYER *et al.* 2088; FRISCH *et al.* 2011; INGERSOLL 2012) refer to aulacogen formation as a particular stage (often, late Precambrian) in the evolution of cratons, which has been a “classic” concept in the Soviet/Russian geoscience community.

The Donets Basin as aulacogen

The Donets Basin (*s. lato*) is an elongated tectonic structure stretching across the southern part of the East European Craton, on the territories of eastern Ukraine and southwestern Russia (Fig. 2). It consists of several segments, namely (from west to east) the Pripyat Trough (Depression), the Dniepr–Donets Basin (Depression), the Donbass (also spelled Donbas) Fold Belt (Donets Basin *s. str.*), and the Karpinsky Swell (STEPHENSON *et al.* 1996; MAYSTRENKO *et al.* 2003; RUBAN & YOSHIOKA 2005). The Donets Basin is a “classic” aulacogen (PAFFENGOL'TS 1978; POTAPOV 1996; STEPHENSON *et al.* 1996; NATAL'IN & ŞENGÖR 2005; BOGGS 2006), which was extended and subsided to allow deposition of thick late Paleozoic sedimentary deposits; then it was compressed with consequent folding and faulting (see brief review and references in RUBAN & YOSHIOKA 2006; SACHSENHOFER *et al.* 2012). However, Soviet geologists interpreted the same structure to be a geosyncline (see review in LA'ZKO 1975). Modern views on the nature of the Donets Basin, which somewhat differ, are summariz-

ed by STEPHENSON *et al.* (1996), MAYSTRENKO *et al.* (2003), SAINTOT *et al.* (2003a,b), KOSTJUTCHENKO *et al.* (2004), NATAL'IN & ŞENGÖR 2005; RUBAN & YOSHIOKA (2005), RUBAN (2007), MEIJERS *et al.* (2010), and SACHSENHOFER *et al.* (2012).

According to the most recent synthesis of the available knowledge (SACHSENHOFER *et al.* 2012), the opening of the Donets Basin occurred in the Late Devonian when the pre-existing Sarmatian Craton was divided into two parts, which are known today as the Ukrainian and Voronezh massives (STEPHENSON *et al.* 1996; RUBAN & YOSHIOKA 2005). We can not exclude the possibility that emplacement of a mantle plume could trigger, or at least contribute to, the appearance of this basin (WILSON & LYASHKEVICH 1996; RACKI 1998; BRINK 2009; SACHSENHOFER *et al.* 2012). The Donets basin, however, might have inherited some older structures (e.g., POTAPOV 1996). Strong post-rift subsidence occurred in the late Paleozoic, and was followed by an inversion and uplift (SACHSENHOFER *et al.* 2012). The age of the compressional event(s) is still debated, but it ranges from the Permian to the Cretaceous (SAINTOT *et al.*, 2003b; NATAL'IN & ŞENGÖR 2005; RUBAN & YOSHIOKA 2005; see also brief review in SACHSENHOFER *et al.* 2012). RUBAN & YOSHIOKA (2005) and RUBAN (2007) discussed the evolution of the Donets Basin in a broader context (similar views were also expressed independently by NATAL'IN & ŞENGÖR (2005)). These authors followed earlier ideas expressed by ARTHAUD & MATTE (1977). According to these studies, the Donets Basin was formed as the result of strike-slip displacements in the Variscan and adjacent structures. It is possible that dextral displacements along the southern margin of the East European Craton detached from the Ukrainian block and opened the elongated basin between this new terrane and the rest of the craton in the late Paleozoic (Fig. 2). Changes in the direction of displacements along the major shear zone located along the southern margin of the East European Craton in the early Mesozoic resulted in compression of the thick sedimentary complexes that were accumulated in the above-mentioned basin. This scenario requires some refinement, but it relates the nature of the Donets Basin to forces that are much larger in scale than those responsible only for the evolution of the East European Craton. The noted major shear zone was an element of the global system of shear zones, which stretched across Gondwana and the northern Palaeo-Tethyan margin (RUBAN 2007) (Fig. 2).

If the Donets Basin is an aulacogen, how does its nature, characterized above, fit the various definitions of aulacogen formation? If we take the only descriptive meaning of the term “aulacogen” from the Soviet literature of the mid-20th century (see above), there is no difficulty in applying this term to the Donets Basin. However, it is impossible to relate the term “aulacogen” to the Riphean stage in the evolution of the

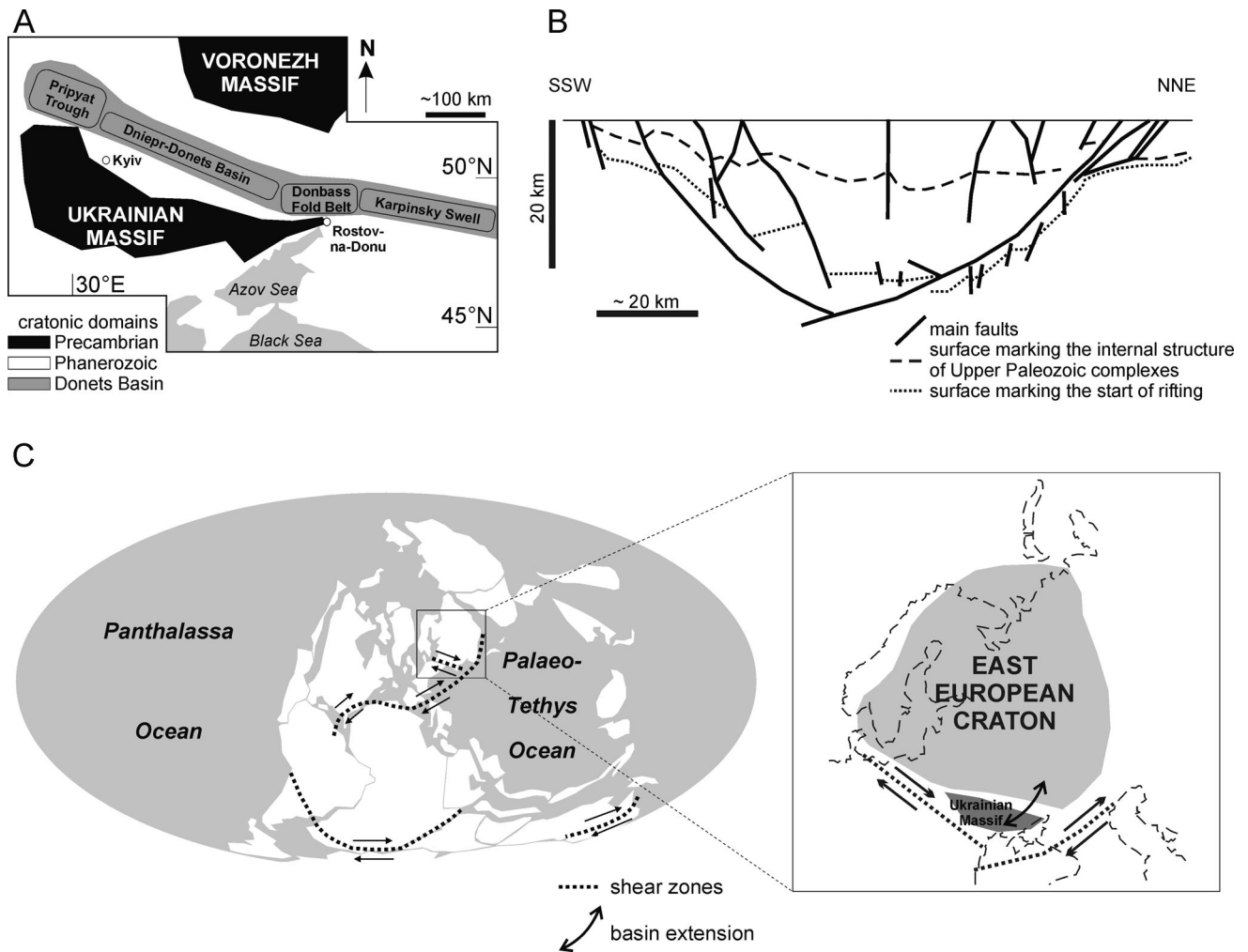


Fig. 2. Geological outline of the Donets Basin. **A**, Schematic location of the Donets Basin and its main segments (adapted and simplified from MAYSTRENKO *et al.* 2003 and RUBAN & YOSHIOKA 2005). **B**, Generalized profile across the Donbass Fold Belt (modified from MAYSTRENKO *et al.* 2003; SACHSENHOFER *et al.* 2012). **C**, Late Paleozoic development of the Donets Basin (after RUBAN & YOSHIOKA 2005; RUBAN 2007 with slight modifications; base plate tectonic reconstruction is simplified from SCOTESE 2004).

young East European Craton. If this basin inherited any Precambrian lineaments (e.g., POTAPOV 1996), then it was formed in the mid-Paleozoic, when the craton was already “old”. Moreover, as said above, the forces responsible for the formation of the Donets Basin were different from those responsible for the evolution of the craton. From various definitions of aulacogens proposed in international publications, that of INGERSOLL (2012) differs especially from what occurred in the Donets Basin. In particular, there is no any clear evidence that the Donets Basin evolved as the third arm of a three-rift system.

Recently, a new classification of rift structures has been proposed; plume-related, subduction-related, mountain-related, and transform-related rifts are distinguished on the basis of the tectonic environments that were present at their formation (MERLE 2011). Is it possible to apply this classification to the Donets

Basin? Features of two types of rifts can be found in the Donets Basin. First, we already suggested that the emplacement of a mantle plume could facilitate or even provoke the Donets rift formation in the Late Devonian (WILSON & LYASHKEVICH 1996; RACKI 1998; BRINK 2009; SACHSENHOFER *et al.* 2012), and the activity of mantle plumes might have contributed to the evolution of this rift at the later stages (ALEXANDRE *et al.* 2004). If so, this plume-related rift (*sensu* MERLE 2011) is to be compared with the East African continental rifts (CORTI 2009, 2012). Second, the Donets Basin developed in the strike-slip environment (NATAL'IN & ŞENGÖR 2005; RUBAN & YOSHIOKA 2005; RUBAN 2007). In this case, it bears features typical of transform-related rifts described by MERLE (2011). It is important to note that judging the Donets Basin as aulacogen does not clarify its nature. In contrast, the application of the new classification of rift structures

(MERLE 2011) permits us to indicate the mechanism of its formation exactly.

Discussion and conclusion

Undoubtedly, the geologic recognition of aulacogens, and the intense study of these formations by Soviet/Russian specialists, played a great role in deciphering the geologic history of cratons. Because of this, I do not tend to judge the results of *these* studies too critically, although when doing so it is important to also consider the alternative understandings of the term “aulacogen” (stressed already by KOSYGIN 1969), and the fact that aulacogen development is not necessarily associated with cratonic evolution (see about the nature of the Donets Basin). A greater problem is the “diffuse” meaning of the term “aulacogen” in the modern *international* geoscience literature. This meaning differs somewhat from the original definition, because it attempts to explain aulacogens genetically in terms of the plate tectonics. Moreover, the genetic treatment of aulacogens implies formational explanations that are not relevant for all possible aulacogens, including such typical aulacogens as the Donets Basin. Instead, the new tectonic nomenclature provides better causative descriptions of basins than “simply” judging them to be aulacogens. For example, the classification of rift structures proposed by MERLE (2011) provides a proper tectonic terminology from which we can infer the nature of the Donets Basin formation (combined plume- and transform-related).

Do the considerations presented above imply that the term “aulacogen” is improper or failed, as has been suggested by FRISCH *et al.* (2011). In my opinion, it is equally wrong to preserve one term that does not fit the present needs as it is to abandon it, especially if it remains relatively frequently used (Fig. 1). I propose the following solution to this dilemma: the term “aulacogen” may still be used, but for only those tectonic structures and sedimentary basins that were already judged aulacogens, e.g., the Donets Basin, the Pachelma Trough, and the Vyatka Aulacogen of the East European Craton (KOSYGIN 1969; BOGGS 2006). For these, “aulacogen” is the historically correct term. Moreover, the original Soviet meaning of the “aulacogen” is merely descriptive, which simplifies the preservation of the regional use of this term. Similarly, such terms “flysch” and “molasse” are used for particular sedimentary packages in the sedimentological, stratigraphic, and tectonic literature. As for other or future tectonic investigations, the term “aulacogen” should be avoided. The new classifications, such as those proposed by MERLE (2011), provide us with a proper tectonic terminology.

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Резиме

Аулакогени, Доњецки басен (источна Украјина, југозападна Русија), и нова класификација рифтова: према исправној терминологији

Термин “аулакоген” је увео познати руски геолог Н.С. Шатскиј средином двадесетог века. Од тада је овај термин прихваћен од стране истраживача ван граница бившег СССР и Русије. Међутим, оправданост овог термина оспоравали су неки тектоничари. Аутор покушава да одговори да ли је “аулакоген” подесан термин за употребу у контексту модерне тектонике. У том циљу: 1) његово оригинално, као и садашње значење, су испитивани и упоређивани, и 2) разматрана је алтернативна употреба нове класификације рифтних структура да опише типичне аулакогене (као Доњецки басен у источној Европи). Совјетски геолози су дефинисали термин “аулакоген” као издужену интракратонску структуру, често запуњену набраним дебелим седиментима. Занимљиво је да се формирање аулакогена често приписује одређеном стадијуму у еволуцији кратона, где су млађе платформе подвргнуте разорним деформацијама. Покушаји да се промени ово значење, од описног до генетског, довело је до широког спектра мишљења у дефинисању аулакогена. Неки истраживачи доводе их у везу са континенталним рифтовима или рововима. Аутори неких савремених несавјетских/руских публикација нагињу употреби термина “аулакоген” са извесним разликама, у контексту тектонике плоча.

Ни једна књига или пак поглавље књиге, који су коришћени овом приликом, не упућују на то да би аулакоген представљао посебну фазу (често касни прекамбријум) у еволуцији кратона, што је иначе било класично тумачење међу совјетским/руским геолозима. Насупрот томе, ако погледамо савремене радове публиковане у међународним часописима видећемо да се термин “аулакоген” односи на басене везане за континентална продужења и/или суперконтинентална издизања, и многи од ових басена су касне прекамбријске старости.

Доњетски басен у ширем смислу је једана издужена тектонска структура која се пружа дуж јужног дела источно европског кратона, на територији источне Украјине и југозападне Русије. Идући од запада ка истоку састоји се од неколико делова: Припјат трог (депресија), Дњетро-доњетски басен (депресија), Донбаски разломни појас, који су “класични” аулакогени. Ако је тако, како се његова природа, поменуто горе, подудара са различитим дефиницијама формирања аулакогена? Ако узмемо само описно значење термина “аулакоген” из совјетске литературе средином двадесетог века, нема потешкоћа у примени овог термина за Доњетски басен. Мађутим, немогуће је довести термин “аулакоген” у везу са Рифејским стадијумом у еволуцији млађег источноевропског кратона. Ако је овај басен имао неке прекамбријске особине, тада је он формиран у средњем палеозооку, када је кратон већ био формиран. Шта више, силе одговорне за формирање Доњетског басена су различите од оних које су учествовале у еволуцији кратона. Важно је напоменути да тумачењем Доњетског басена као аулакогена не објашњава и његово порекло. Примена нове класификације рифтних структура дозвољава нам да прецизно укажемо на механизам његовог формирања. У Доњецком басену могу се уочити карактеристике два типа рифтова. Прво, положај плуме из омотача могао је да олакша или чак да проузрокује формирање Доњетског рифта у касном девону. У том случају, ови плуме рифтови могу се корелисати са источноафричким континенталним рифтовима. Друго, Доњетски басен се развијао у разломној средини. У том случају он има особине типичне за трансформне рифтове.

Аутор предлаже следеће решење овог питања: термин “аулакоген” може се још употребљавати, али само за оне тектонске структуре и седиментационе басене које се већ сматрају аулакогеним, нпр. Доњетски басен, Печелма трог, Вијатка аулакоген источноевропског кратона, за њих је “аулакоген” исправан термин.

Термини као “флиш” и “моласе” су у употреби за поједине седиментне пакете у седиментолошкој, стратиграфској и тектонској литератури. За будућа тектонска испитивања треба избегавати термин “аулакоген”. Нове класификације крупних тектонских структура упућују нас на одговарајућу тектонску терминологију.