ANNALES SOCIETATIS GEOLOGORUM POLONIAE
ROCZNIK POLSKIEGO TOWARZYSTWA GEOLOGICZNEGO

v. 54-3/4: 281 – 291 Kraków 1984

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FLYSCH AND MOLASSE: THE ELUSIVE MODELS

Flisz i molasa: złudne modele

Andrew D. Miall: Flysch and Molasse: the elusive models.
Ann. Soc. Geol. Poloniae, 54-3/4: 281 – 291, 1984 Kraków.

Abstract: The terms flysch and molasse are survivors from geosyncline theory. Both words are in active use but a survey of recent literature shows that there is no consistent definition. Some workers emphasize a combination of lithofacies assemblage and orogenic setting, others extend the definitions, particularly that of flysch, to any occurrence of the typical lithofacies assemblage. Definitions of flysch and molasse with reference to orogenic stage (pre-, early, late, post-orogenic) or to orogeny in general are virtually meaningless because of the diachronous nature of orogeny and its varied styles. The terms convey now more confusion than useful meaning, and it is recommended that they be abandoned.

It is recommended that major flysch and molasse pulses be given stratigraphic names of group or supergroup rank, to facilitate communication. Imprecise generalization can thereby be avoided, and each major stratigraphic unit can readily be linked to specific local tectonic events.

Key words: flysch, molasse, definition of flysch.

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manuscript received: April, 1983 accepted: July, 1983

Treść: Terminy flisz i molasa są reliktami teorii geosynklinalnej. Oba te terminy są w powszechnym użyciu, chociaż nie są one definiowane i stosowane w sposób jednoznaczny. Niektórzy autorowie w swoich definicjach kładą nacisk na połączenie charakterystycznego zespołu litofacji z określonym rejonem orogenicznym, inni rozciągają definicje, szczególnie fliszu, na jakiekolwiek wystąpienie typowej asocjacji facjalnej. Definiowanie fliszu i molasy w odniesieniu do stadium orogenicznego (pre-orogeniczne, wczesno, późno i post-orogeniczne) jest pozbawione sensu ze względu na diachroniczny charakter procesów orogenicznych i ich zróżnicowany styl. W związku z powyższym autor uważa, że dalsze stosowanie obu tych terminów powinno być zarzucone. Zaleca się natomiast nadawanie nazw litostratygraficznych o randze grup lub nadgrup większym kompleksom fliszowym i molasowym. W ten sposób uda się uniknąć fałszywych generalizacji, a każdą z tych jednostek litostratygraficznych można będzie łatwo powiązać z określonymi, lokalnymi wydarzeniami tektonicznymi.

INTRODUCTION[1]

The terms flysch and molasse are living fossils representing the virtually extinct geosyncline theory. The thesis of this paper is that they should now be abandoned as terms that embody more confusion than useful information. The use of the terms has been widely debated (e.g., Hsü, 1970; Reading, 1972; Van Houten, 1973) and it is not the writer's purpose to review or summarize this debate, which raged even before the advent of plate tectonics. However, a brief introduction is required.

The term flysch was introduced by Studer (1827a, b) for a sequence of Upper Cretaceous sandstones and mudstones in the Siemmenthal region of Switzerland. As noted by Dżułyński and Walton (1965) and Dżułyński and Smith (1964) the term was originally used purely in a lithological sense, without stratigraphic or tectonic implications. Many studies since then showed that similar units occurred in a similar stratigraphic and structural position in many parts of the Alpine "geosyncline", for example, the Carpathian flysch of southern Poland (Książkiewicz, 1958, 1960; Dżułyński and Walton, 1965). As a result the term flysch acquired a tectonic meaning, and became an integral part of the "geosynclinal cycle".

Molasse had a similar origin, as a Swiss lithological term (Bertrand, 1897; Haug, 1900), and was gradually categorized as a "late orogenic" product, in the geosynclinal cycle (e.g., Aubouin, 1965).

The continued use of flysch and molasse in recent literature reflects their apparently useful linking of tectonic and stratigraphic concepts. This is clearly stated in the definitions contained in the AGI Glossary of Geology (Bates and Jackson, 1980):

Flysch: "an extensive, preorogenic sedimentary formation representing the totality of the flysch facies deposited in different troughs, during the later stages of filling of a geosynclinal system, by rapid erosion of an adjacent and rising mountain belt at a time directly previous to the main paroxysmal (diastrophic) phase of the orogeny or when initial diastrophism had already developed interior ridges exposed to erosion; specif. the Flysch strata of late Cretaceous to Oligocene age along the borders of the Alps, deposited in the foredeeps in front of northward-advancing nappes rising from beneath the sea, before the main phase (Miocene) of the Alpine orogeny. (The) term... has been loosely applied to any sediment with nearly all of the lithologic and stratigraphic characteristics of a flysch, such as almost any turbidite."

Molasse: "An extensive, postorogenic sedimentary formation representing the totality of the molasse facies resulting from the wearing down of elevated mountain ranges during and immediately succeeding the main paroxysmal (diastrophic) phase of an orogeny, and deposited considerably in front of the preceding

[1] Editorial note. We feel that many geologists active in the field of flysch and molasse research will not follow Dr. Miall's opinions neither will be satisfied with his solution of presented problem. Nevertheless, publishing this rather controversial paper we hope to provoke a discussion which will clarify, at least partly, some of the existing misinterpretations concerning these terms.

flysch; specif. the Molasse strata, mainly of Miocene and partly of Oligocene age, deposited on the Swiss Plain and Alpine foreland of southern Germany subsequent to the rising of the Alps."

The European usage of the terms is emphasized in these definitions. Both terms are in continual use for describing the appropriate Cretaceous and Cenozoic sediments throughout the Alpine chain from France to Romania (e.g., Gigot *et al.*, 1974; Stefanescu, 1980; Sandulescu, 1980; Van Houten, 1974, 1981; Burchfiel and Royden, 1982). The terms have also been widely used in other orogenic belts, as exemplified by the following selected references to recent literature: Cretaceous-Tertiary of the Canadian Rocky Mountains (Eisbacher *et al.*, 1974; Eisbacher, 1974, 1981), Cenozoic of the Himalayan region (Graham *et al.*, 1975; Visser and Johnson, 1978; Parkash *et al.*, 1980; Andrews-Speed and Brookfield, 1982), Cenozoic of Japan (Tandon and Okada, 1982; Okada and Tandon, 1982), Lower Paleozoic of Appalachians (Graham *et al.*, 1975; Lash, 1982), Late Paleozoic of Appalachians (Rust, 1981; Donaldson and Shumaker, 1981); Late Paleozoic (Variscides, Hercynides) of western Europe (Lutzner, 1981; Tenchov and Yanev, 1980; Vozarova, 1980); Precambrian of Canadian Shield (Hoffman, 1980; Ricketts, 1981).

Most but, significantly, not all these workers adhere more or less to the definitions of flysch and molasse quoted above. The emphasis on lithofacies assemblage and on orogenic setting are the main themes throughout. However, when examined in a rigorous plate tectonics context these definitions break down in several ways:

1. Their tectonic setting has not been clearly defined. Lithofacies assemblages similar to those of the type Alpine flysch and molasse occur in numerous "non-orogenic" tectonic settings.

2. Their supposed relationship to orogenic stages (pre-, early, late and post-orogenic) is meaningless.

3. They have not been used in a consistent way to indicate particular lithofacies assemblages.

These problems are examined in detail below.

TECTONIC SETTING

Most workers, when asked to define flysch and molasse, would emphasize the association with orogeny, as in the Glossary definitions quoted above. However, in several important review papers this association has been set aside. Thus Reading (1972), Mitchell and Reading (1978) and Nachev (1980) defined flysch in the following way (quoted from Reading, 1972):

> "Any thick succession of alterations of sandstone, calcarenite or conglomerate with shale or mudstone, interpreted as having been largely deposited by turbidity currents or mass flow in a deep water environment, within a geosynclinal belt."

As Reading (1972) stated, this "begs the question of what is a geosyncline." He went on to describe six specific types of basin (or geosyncline) where this lithofacies association commonly occurs. In plate tectonic terms these include divergent continental margins, forearc and back-arc basins, strike-slip fault basins and remnant ocean basins (intra-suture embayments). By any definition of orogeny, a divergent continental margin is not actively orogenic (neither is it "passive", to quote another misleading term). Therefore, to carry Reading's definition to its logical conclusion the continental rise prism of the modern Atlantic border, the thick, glacially derived sediment gravity flow deposits of the Antarctic shelf, and the Cenozoic submarine fan deposits of the Viking-Central Graben of the North Sea should all be classified as flysch. Some apparently "pre-orogenic" flysch deposits are genetically completely unrelated to orogeny. For example, the Ordovician deep water sediments of the St. Lawrence River region in Quebec could be described as pre-Taconic flysch but, in fact, represent the continental rise prism on the divergent margin of Lapetus Ocean, or of a marginal back-arc basin, prior to orogenic closure of the ocean.

A similar, broad definition of molasse has not been offered. Thus Van Houten (1981) emphasized that "molasse has been widely acknowledged to be a post-paroxysmal, late orogenic detrital deposit," typically developed in foredeeps along the flanks of collision orogenes. He went on to say "molasse-like (molassoid) deposits have accumulated in discordant late-orogenic successor basins that formed within an orogen ... these rocks have commonly been called intramontane (rarely intradeep or intermontane) molasse." He stated that "the possibility that basins of this sort may reflect on extensional regime warrents caution in applying the name molasse with its implied development in a foredeep." Mitchell and Reading (1978) defined molasse as "any thick succession of continental deposits ... which were formed as a result of mountain building."

If flysch and molasse are to be defined consistently, we are faced with two alternatives: either to emphasize orogenic setting for both terms or to discard it altogether. In the latter case molasse could include the Cenozoic to recent cratonic fluvial and eolian deposits of Lake Eyre Basin, Australia, the Cenozoic fluvial-deltaic complexes of the Gulf Coast, rift-basin fluvial and lacustrine sediments of East Africa, and the fluvioglacial sandur plains and fan deltas of Iceland and Alaska. Miall (1981) defined twelve distinct plate tectonic settings in which molasse-like lithofacies assemblages may accumulate. Examples of "non-orogenic" flysch have been noted above. It is doubtful if many workers would accept such definitions.

The alternative approach, of emphasizing the genetic association with "orogeny," is no more satisfactory. Plate tectonic theory shows us that compressive faulting, folding, metamorphism and igneous activity (the hallmarks of orogeny) occur in a wide variety of plate settings. The "Caledonian," "Laramide" and "Alpine" orogenies encompass every possible permutation of subduction, arc and continent rotation and collision, microplate movement and transform faulting. Even extensional movements, such as short-lived spreading centres, are an integral part of orogenic activity, as in the modern Indonesian region (Hamilton, 1979). It is no longer useful simply to label a fold belt or a clastic wedge as orogenic.

It might be argued that Van Houten's definition of molasse is sufficiently tight and well defined to permit a simple application to other areas, but this is not the case. The "type" molasse is the Cenozoic clastic wedge of Switzerland and southern Germany, derived from the rising Alpine nappes and deposited in the adjacent subsiding foreland (or foredeep) basin (Van Houten, 1974, 1981). Plate tectonic reconstructions by Devey *et al.* (1973) showed that the Alps of Switzerland were generated by collision of Europe with the Carnic microplate along a southward dipping subduction zone. The molasse foredeep is therefore developed on the subducting plate in a forearc position. The Siwalik molasse of the Himalayan region has a similar tectonic setting. However, other apparently similar foredeep molasse basins are located in a retroarc position, that is, on the overriding plate. The Cretaceous-Tertiary molasse of the Rocky Mountains region, the Karoo Group of South Africa, and the Devonian Anglo-Welsh Cuvette (Old Red Sandstone) have similar tectonic settings. The structural style of all these foreland basins, with their flanking fold-thrust (A-subduction) belts, is similar, but they represent two fundamentally different plate settings.

The molasse of interior "successor" basins represents an even greater variety of tectonic styles. Thus the Pannonian molasse basin in the Balkan region is an extensional back-arc basin behind the Carpathian arc, and shows considerable evidence of syndepositional strike-slip faulting (Burchfiel and Royden, 1982). Flysch and molasse in the Po Basin, Italy, represent the fill of a remnant ocean basin between colliding microplates (Dewey *et al.*, 1973). The Kutei Basin of Kalimantan, Indonesia, contains more than 4 km of Miocene to Recent deltaic sediments formed in a small ocean basin developed over a local spreading centre (Hamilton, 1979). The Indonesian region in general is undergoing convergent tectonics and could be said to be an active orogenic belt, and the Kutei clastic wedge would seem to be a good example of a modern internal molasse basin, even though it is an extensional setting.

Many of the interior molasse basins of the Canadian Rocky Mountains were formed along strike-slip faults (Long, 1981). Friend (1981) suggested that many of the Old Red Sandstone basins of the Caledonian orogen were similarly controlled. Major mountain belts can be generated by transpressive orogeny, as in present-day South Island, New Zealand. The mountains there are flanked to the east by the Canterbury Plains, where a molasse-like apron of nonmarine sediments is accumulating. Active flysch basins lie offshore (Spörli, 1980). Dewey (1980) demonstrated that oblique convergence and strike-slip faulting are an integral part of most convergent plate boundaries, and Reading (1980) and Miall (1981) discussed the implications of this pervasive tectonic element for sedimentation in orogenic belts. Do we include those basins where strike-slip faulting has been a major genetic control in our definition of orogenic basins? Would we refer to the fluvial-lacustrine fill of such classic strike-slip basins as the Ridge Basin (California) or the Hornelen Basin (Norway), as molasse? I doubt it.

To conclude this section we can therefore pose the question: for the purpose of defining flysch and molasse, how do we define orogeny? The only possible answer is that it is whatever the individual worker defines it to be for the purpose of a particular project. This does not make for a very satisfactory terminology.

OROGENIC STAGE

Amongst the surviving misconceptions of geosyncline theory is the idea that flysch is pre- or early-orogenic, while molasse is late- to post-orogenic. This fallacy was noticed some years ago (e.g., Coney, 1970) and is easy to disprove by detailed examination of any orogenic belt. As Dewey (1975, 1977) has shown, orogeny is diachronous; each part of any mobile belt will be in a different stage of tectonic evolution at any given time, because of oblique convergence and the progressive collision of continental plates having irregular margins. Sedimentary basins (or any other element) in a mobile belt are therefore only early or late with respect to specific local tectonic events along that belt.

As an example, consider the Himalayan suture. Typical molasse is accumulating in the Indo-Gangetic Plain at the present day, while the Bengal Fan represents the world's largest modern flysch depositional system. The Bengal Fan is fed by sediment eroded from and bypassing the molasse basin. This entire depositional complex is synorogenic. The Bengal Fan may have started to form earlier (Oligocene) than the molasse (Miocene) but both are now forming at the same time. Toward the southeast the Bengal Fan is being subducted beneath the Sunda Arc. It is therefore pre- to synorogenic with respect to the subduction tectonism. Himalayan uplift may or may not have climaxed. Both flysch and molasse are therefore also late-orogenic and will obviously continue to form for millions of years. Continued northward drift to the Indian-Australian plate may lead to the development of a new subduction zone along the southern margin of India. The Bengal Fan would be subducted and would clearly be pre-orogenic with respect to this new tectonic element.

Many other modern and ancient examples could be quoted. Clearly the concept of orogenic stage should be abandoned.

LITHOFACIES ASSEMBLAGES

The AGI Glossary definitions of flysch and molasse lithofacies, quoted earlier, have been followed by most workers. However, adherence to outmoded concepts of orogenic stage has led recently to several misleading analyses.

Crostella (1977) discussed the Banda Arc in Indonesia. The island of Timor represents the collision of the Australian plate with the north-dipping subduction zone of the Banda Arc, as was clearly shown by Hamilton (1979). Crostella arrived at a different plate tectonic interpretation, but this is not the point to be argued here. Crostella (1977) referred to a "Miocene tectonic climax" responsible for much of the structural deformation of Timor. Sedimentary basins post-dating this climax were therefore labelled "postorogenic" and, presumably this is why they were also referred to as "molasse" basins. However, the sediments in these basins flanking Timor consist of marine calcilutites, marls, tuffs, chalks, reef limestones and turbidite sands deposited in "bathyal" environments!

Tandon and Okada (1982) discussed continental and arc collisions. They stated "the development of molasse basins is considered to be a late to post-orogenic event in zones of collision orogenesis. The character of the lithofacies in the molasse basins would depend upon the nature of the colliding plates...". Collisions between arcs and microcontinents may not result in the elevation of significant land masses, so that the lithofacies of molasse basins "could vary from alluvial to shallow marine to even deep marine. The molasse basins of Hokkaido contain a characteristic fill of turbidites and resedimented conglomerates (deep water facies)." They stated that "the primary consideration for a deposit to qualify as molasse is its post- to late orogenic character" and suggested that "the terms flysch and molasse when applied in the context of collision orogenesis need to be shorn of their implicit lithological and facies considerations." It is hard to see what would be gained by so doing.

DISCUSSION AND RECOMMENDATION

There is no doubting that flysch and molasse represent widespread, distinctive lithofacies associations (consanguineous associations of Fairbridge, 1958). There is also no doubt that some examples of these associations occur at particular stages of arc or continental collision. However, as this review has shown, so many inconsistencies and misconceptions are now apparent that the two terms are quite inadequate to convey the breadth and depth of knowledge that has now accumulated about sedimentation and plate tectonics.

The question naturally arises that, if flysch and molasse are to be abandoned, with what should we replace them? One of the most important lessons of plate tectonics is that every plate undergoes an unique history. The possible combinations of rifting, spreading, convergence and oblique slip are virtually infinite (Dewey, 1975, 1982). Consequently each orogenically-related sedimentary suite itself has an unique history, which is only obscured by the use of a generalized terminology (Miall, in press). The erection of a set of defined subtypes of flysch and molasse to encompass the tectonic variability could not possibly succeed because of the enormous variety of models that would be required. Additional terms would also be needed for the non-orogenic varieties of flysch-like and molasse-like lithofacies assemblages, examples of which have been given earlier.

It is suggested that the best solution is the correct use of key stratigraphic names. Formation, group, and other formal stratigraphic units are defined on the basis of lithology, which itself is a reflection of depositional environment and tectonic setting. Local names can therefore be used to convey the necessary tectonic associations. For example, the Jurassic-Tertiary molasse of Alberta, Canada, has been divided into two major clastic pulses, the Kootenay-Blairmore Assemblage and the Belly River-Paskapoo Assemblage, using four local formation names (Eisbacher *et al.*, 1974). Eisbacher (1981) discussed the origins of these assemblages in terms of Cordilleran plate tectonics.

It may be desirable to erect a new lithostratigraphic term (group or supergroup) to encompass an entire flysch or molasse pulse. This can be accomplished following standard stratigraphic procedures and has the advantage that the geographic and stratigraphic limits of the unit can be tightly defined, permitting a precise description and tectonic interpretation. Alternatively, use may be made of the formal diachronic terms (episode, phase, etc.) recently defined by the North American Commission on Stratigraphic Nomenclature (1983). Informal use of such terms as assemblage or megacycle is also acceptable.

The adventage of this method is that local stratigraphic names are restricted in their applicability and cannot readily be used for imprecise generalization in other areas. A modest proliferation of names is unavoidable, but this reflects the tectonic diversity of the real world. The definition of a few well-chosen higher--rank names for major, widespread sequences would be a very useful development from the point of view of international communication. For example, the term Catskill Delta, although it has never been properly defined, is widely understood in North America as a particular molasse pulse of the Appalachian mobile belt (this is Barrell's old term and, of course, only limited parts of the clastic wedge are now interpreted as deltaic). In Europe the existing confusion of local or national stratigraphic names could be simplified by the efforts of an IGCP working group established to recognize, define and name the major flysch and molasse pulses in the various tectonic provinces of the Alpine region.

CONCLUSIONS

In these days of increasingly precise environmental interpretation and plate tectonic reconstruction there is no longer any excuse for the use of sloppy terminology or lazy generalization. It should be clear from this review that the prevailing attitude toward flysch and molasse is now essentially that of Humpty Dumpty, who said "when I use a word it means just what I choose it to mean – neither more nor less." And we all know happened to him.

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