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НЕОТЕКТОНИЧЕСКОЕ ПОДНЯТИЕ ГОР И ГЕОМОРФОЛОГИЯ

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Горы — это рельеф, созданный эрозией после вертикального поднятия или “горообразования”. Последнее часто считают синонимом “орогении”, под которой в настоящее время подразумевают формирование структур в поясах складчатости. Общепринятое представление о том, что складчатость и горообразование происходят одновременно во многом неверно. Многие горы сложены не смятыми в складки толщами, гранитами и вулканическими породами; следовательно, нет прямой связи складчатости и горообразования. Во многих случаях, где в основе гор лежат складчатые толщи, складчатость предшествовала планации и поднятию. Значит возраст гор — не возраст последней складчатости (если она вообще была), а возраст вертикального поднятия. Поскольку горные территории не ограничены областями развития складчатых пород, боковое сжатие не является необходимым условием для объяснения поднятия.

Обобщение материалов о времени поднятия гор по всему миру показывает, что главная фаза тектонических поднятий началась около 6 млн л. н., и бóльшая часть поднятия произошла в последние 2 млн л. Этот период известен как неотектоническая эпоха. Это глобальное явление, охватывающее, в том числе, образование гор на пассивных континентальных окраинах и внутри континентов.

Некоторые гипотезы образования гор плохо согласуются с данной хронологией. Несостоятельность части гипотез в том, что они подходят только для объяснения формирования гор из складчатых пород на континентальных окраинах. Многие обусловливают вертикальные поднятия боковым сжатием, но вертикальные поднятия и сами по себе могут формировать горы.

Неотектонический период очень существенен для геоморфологии, климатологии и глобальной тектоники. Он не увязывается с общепринятыми геоморфологическими теориями, такими как циклы эрозии Дэвиса или Кинга. Неотектонические поднятия могли вызвать несколько циклов эрозии, но большинство поверхностей выравнивания значительно древнее неотектонической эпохи. Растущий рельеф, ассоциирующийся с неотектоническим поднятием, повлиял на темпы денудации и осадконакопления, а также на климат позднего кайнозоя.

Неотектонический период не согласуется с теорией плитотектоники, которая объясняет образование гор сжатием на активных окраинах континентов. Согласно ей горы в других районах созданы аналогичными процессами в более древние эпохи, но это не объясняет молодой возраст горных поднятий во внутриконтинентальных районах и на пассивных окраинах континентов. Субдукцией, которая как предполагается длится сотни миллионов лет, невозможно объяснить поднятия, происходящие по всему миру в последние несколько миллионов лет.

Геоморфологи должны руководствоваться только результатами собственных исследований, а не теоретическими построениями, исходящими из коллизии литосферных плит или гипотез эволюции рельефа.

Ключевые слова: неотектоника, орогенез, складчатость, поверхность выравнивания, тектоника литосферных плит, пассивные континентальные окраины, великие уступы.

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NEOTECTONIC MOUNTAIN UPLIFT AND GEOMORPHOLOGY

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S u m m a r y

Mountains are topographic features caused by erosion after vertical uplift or ‘mountain building’. Mountain building is often confused with ‘orogeny’, which today means the formation of structures in fold belts. The common assumption that folding and mountain building go together is generally untrue. Many mountains occur in unfolded rocks, granites and volcanic rocks, so there is no direct association of folding and mountain building. In those places where mountains are underlain by folded rocks the folding pre-dates planation and uplift. The age of mountains is therefore not the age of the last folding (if any) but the age of vertical uplift. Since mountains are not restricted to folded rocks, lateral compression is not required to explain the uplift.

A compilation of times of uplift of mountains around the world shows that a major phase of tectonic uplift started about 6 Ma, and much uplift occurred in the last 2 Ma. This period is known as the Neotectonic Period. It is a global phenomenon including mountains on passive continental margins, and those in deep continental interiors. Several hypotheses of mountain building have problems with this timing. Some fail by being only able to make mountains out of folded rock at continental margins. Many translate the vertical uplift into lateral compression, but vertical uplift alone can create mountains.

The Neotectonic Period has important implications for geomorphology, climate and global tectonics. In geomorphology it does not fit into conventional theories of geomorphology such as Davisian or King cycles of erosion. Neotectonic uplift might initiate several cycles of erosion, but most planation surfaces are much older than the Neotectonic Period. The increasing relief associated with Neotectonic uplift affected rates of erosion and sedimentation, and also late Cenozoic climate.

The Neotectonic Period does not fit within plate tectonics theory, in which mountains are explained as a result of compression at active margins: mountains in other locations are said to have been caused by the same process but further back in time. This is disproved by the young age of uplift of mountains in intercontinental and passive margin positions. Subduction is supposed to have been continuous for hundreds of millions of years, so fails to explain the world-wide uplifts in just a few million years.

Geomorphologists should be guided by their own findings, and refrain from theory-driven hypotheses of plate collision or landscape evolution.

Keywords: neotectonics, orogeny, passive continental margins, folding, planation surface, plate tectonics, passive continental margins, Great Escarpments.

Introduction

The idea of a rapid mountain building period has been an accepted idea in Russia for quite a while. Pavlides (1989) first brought the idea to western notice, and he attributes it to Obruchev (1948) which we have not seen. The mountain building period is known as the Neotectonic Period, and was defined by Obruchev as 'Young tectonic movements occurring in the late Tertiary and early half of the Quaternary'. Crustal movement of this period are said to be of first order magnitude in the Earth's history and characterised by epeirogeny. Apparently some Russian workers maintained that the term should be applied only to vertical crustal movement of old cratonic provinces, but this seems to be needlessly restrictive, and Hoshino (1998) considers that the Neotectonic Period also affected the mobile belts — it is a global crustal phenomenon.

Molnar (2007, p. 401) wrote "... if mountain ranges did rise simultaneously across the globe, then a demonstration of that occurrence would surely be among the more important discoveries in the earth sciences". It is not clear just what 'simultaneously' means in a process that is not instantaneous, but here we aim to demonstrate exactly that.

Previously we have assembled evidence that most mountains are products of the uplift of a plain to form a plateau, which may or may not be extensively dissected (Ollier and Pain, 2000). The original plain was usually a planation surface. The age of a mountain or mountain range is thus the age of the vertical uplift, not the last age of folding of rock (if folds are present). For example the mountains of Scandinavia, often called Caledonian Mountains, consist of Precambrian rocks and Palaeozoic sedimentary rocks that were folded in the Caledonian orogeny (Palaeozoic). They were eroded to a low relief surface, and the mountains of today result from Neogene uplift (Japsen et al., 2002, Lidmar-Bergström et al., 2013).

All over the world there is evidence that mountain uplift has been very effective over the last few million years. Our compilation of mountains throughout the world (Table) shows a major phase of uplift occurred in the Plio-Pleistocene. We do not believe this is an artefact of our sampling, as workers all over the world have come to the same conclusion. As Molnar

Table

Some published ages for mountain uplift (in many areas there are precursor movements, and the ages here generally refer to the major or latest uplifts)

Таблица

Некоторые опубликованные данные о возрасте горных поднятий
(во многих районах имели место предваряющие движения, и оценки возраста относятся обычно к основной, более позднее фазе поднятий)

Location	Tectonic Setting	Age of Uplift	References
EUROPE			
Swiss Alps	Active margin	Pliocene-Quaternary/ present	Trumpy, 1980; Wittmann et al., 2007; Wagner et al., 2010; Mey et al., 2016;
Jura		Pleistocene	Holmes, 1965; Madritsch et al., 2010; Székely et al., 2002
Apennines		Latest Pliocene — Middle Pleistocene	Coltorti and Pieruccini, 2000; Coltorti et al., 2008
Austrian Alps		4 million years	de Graaff, 2006
Pyrenees	Interior	Pliocene	Sala, 1984a; Calvet, 1994; Gunnell et al., 2009
Central Cordilleras of Spain		Plio-Pleistocene	Sala, 1984b; de Bruijne and Andriessen, 2002
Baetic Cordillera	Active margin	Upper Miocene — Pliocene	Choubert and Faure-Muret, 1974; Sala, 1984c; Braga et al., 2003; Ollier, 2006a

Location	Tectonic Setting	Age of Uplift	References
Iberian Chain	Interior	Pliocene	Gutierrez, 2006
Bulgaria		Latest Pliocene	Zagorchev, 1992, 2002; Ollier, 2006b
Western Carpathians		Upper Miocene — Pliocene, Quaternary	Földvary, 1988; Fodor et al., 2005
Eastern Carpathians		Pliocene-Quaternary	Zuchiewicz, 1995; Cloetingh et al., 2004, 2005; Necea et al., 2013
Southern Carpathians		2.500 m about 12 Ma; 1000 m about 2 Ma	Rãdoane et al., 2003
Caucasus		Upper Pliocene, Quaternary	Bridges, 1990; Mitchell and Westaway, 1999; Mosar et al., 2010
Ural Mountains		Pliocene-Quaternary	Bridges, 1990; Mikhailov et al., 2002
Sudeten		Pliocene-early Quaternary	Migon and Lach, 1999
Lublin Plateau, Poland		Plio-Pleistocene	Dobrowolski, 2006
Scandinavia	Passive margin	Neogene	Lidmar-Bergstrom et al., 2000, 2013; Lidmar-Bergström and Näslund, 2002
ASIA			
Tibetan Plateau	Continent/ continent	Pliocene-Quaternary	Wu et al., 2001
Himalayas			Zhang, 1998; Kalvoda, 1992; Gansser, 1991; Hodges et al., 2004; Wang et al., 2014
Kunlun Mountains		Late Pliocene-Quaternary	Wu et al., 2001; Zheng et al., 2000; Yuan et al., 2006
Tien Shan		Quaternary	Holmes, 1965; Fang et al., 2002; Buslov et al., 2008
Pamir		Late Cenozoic	Strecker et al., 2003
Altai Mountains		Tertiary, Pliocene — early Pleistocene	Suslov, 1961; Vassallo et al., 2007; De Grave et al., 2009
Transbaikal Mountains		Mid-Tertiary; Pliocene	Ufimtsev, 1990, 1991; Petit and Deverchere, 2006; De Grave et al., 2009
Karakoram		Late Neogene to present	Schroder, 1993; Foster et al., 1994; Dunlap et al., 1998
Shanxi Mountains		Miocene — middle Pleistocene	Li et al., 1998
Japanese Mountains	Active margin	Pliocene — early Pleistocene	Hoshino, 1998; Sueoka et al., 2012
Taiwan		Early Pleistocene — present	Chai, 1972; Ho, 1986 Penglai orogeny; Kirstein et al., 2010; Brown et al., 2012; Ching et al., 2011
Western India	Passive margin	Late Tertiary	Widdowson and Gunnell, 1999
NORTH AMERICA			
Sierra Nevada	Interior	Post-Pliocene	Axelrod, 1962; Hammond et al., 2012
Basin and Range		4 Ma; Miocene	Nitchman et al., 1990; Quigley et al., 2010a
Colorado Plateau		Late Pliocene to Recent	Lucchita, 1979; Trimble, 1980; Sahagian et al., 2002
Bighorn Mountains		Middle Tertiary-Pleistocene;	Thornbury, 1965; Epis and Chapin, 1975
Rocky Mountains		5 million years	Eaton, 1987; Donahue et al., 2013

Location	Tectonic Setting	Age of Uplift	References
Coast Ranges	Active margin	Late Pliocene; 3.5 Ma	Thornbury, 1965; Titus et al., 2011
Canadian Cordillera		Late Miocene — Pliocene	Mathews, 1991; Hyndman, 2010
Canadian Coast Ranges		Modern topography post 2.5 Ma	Farley et al., 2001
Cascade Range		4–5 Ma	Priest et al., 1983; Mitchell et al., 2009
Appalachians	Passive margin	Miocene or younger	Pazzaglia and Gardner, 2000; Stanford et al., 2001; Miller et al., 2013
SOUTH AMERICA			
Colombia	Active margin	Plio-Pleistocene	Kroonenberg et al., 1990
Chile		Pliocene and Pleistocene	Holingworth and Rutland, 1968; Rodríguez et al., 2013
Bolivia		Plio-Pleistocene; 2.5 km post Miocene	Walker, 1949; Leier et al., 2013
Ecuador		Upper Miocene — Plio-Pleistocene	Coltorti and Ollier, 1999
Brazil	Passive margin	Post-Miocene	Peulvast et al., 2008
AFRICA			
Ethiopian Rift	Interior margin	2.9 and 2.4 Ma	Partridge, 1997
Western Rift		3 to 2 Ma	Pickford et al., 1993
Ruwenzori		Within the last 3 million years	Partridge, 1997
South Africa	Passive margin	Pliocene 7–900 m	Partridge, 1998
OTHER REGIONS			
New Guinea Mountains	Active margin	Plio-Pleistocene — recent	Ollier and Pain, 1988; Baldwin et al., 2012
New Zealand Mountains		Pliocene	Suggate, 1982; Williams, 2004
Timor		3 Ma to present	Ollier, 2006c; Nguyen et al., 2013
East Australia	Passive margin	Plio-Pleistocene	Ollier and Taylor, 1988; Quigley et al., 2010b
Greenland		Late Miocene or younger	Weidick, 1976; Benow et al., 2010, 2014; Japsen et al., 2014
Antarctica		Pleistocene	Behrendt and Cooper, 1991

noted, if it true, it has important implications and puts constraints on possible mechanisms and theories in both tectonics and geomorphology.

Neotectonic uplift of mountains appears to be a global phenomenon. It affects so-called Alpine mountains, mountains on passive continental margins, and those in deep continental interiors. The period of uplift is known as the Neotectonic Period, a term coined by Obruchev (1948) and discussed in more detail by Gerbova and Tikhomirov (1982), Mörner (1993) and Ollier and Pain (2000, 2001). Neuendorf et al. (2011) define neotectonics as "the study of the post-Miocene structures and structural history of the Earth's crust".

The six million year period of mountain building, the Neotectonic Period that emerges from our collation appears to have been recognised, at least partially, by earlier workers. It may be the equivalent of the Mediterranean Movement (Aubouin, 1965), the Antillean Revolution (Schuchert, 1935), and the Pasadenian Orogeny (Stille, 1955). Morner (1993) revived Neotectonics, and we published our ideas in 2000 and 2001.

Examples of neotectonic uplift

In this section we can provide only very brief summaries of a small selection of the uplift of mountains, and provide references so that further details can be followed. We have chosen examples to illustrate the wide varieties of evidence and techniques used to determine ages of uplift. In many instances there are several times of uplift, but all include a Neotectonic component, often continuing into the present. We have also chosen examples from different tectonic settings to show that different mountains have different origins and that not all (if any) result from compression.

Europe

The Neotectonic Period in Europe is summarised in Fig. 1.

The European Alps have become a type area for ideas of mountain genesis in regions of folds and nappes. But the nappes have very little to do with the present Alpine topography. Towards the close of the Pliocene the Alps had been reduced to a region of low relief, the complex underlying structures being truncated by an erosion surface. It was then broadly uplifted and eroded to the present spectacular topography. This idea is not new, and was described long ago by Heritsch (1929): "The morphological studies in the Eastern Alps have further proved, from the summit-level (Gipfelflur) of the peaks ... that these erosion-horizons have no sort of relation at all to the geological structure. A further result of research on East-Alpine morphology is the recognition of the fact that the upheaval of the Alps is not connected with the production of the leading features of the internal structures, but that it is related to a later process of elevation, which was of vigorous character".

The Alpine summits levels form a broad arch between the Molasse Basin in the NW and the basin of Po Plain in the SE, with minor undulations along the arch and across it (Fig. 2). Bernoulli et al. (1974) note that "the Gipfelflur levels occur at 2000–3500 m and are well developed in the Eastern Alps where they are of early Miocene to Pliocene age" Alps levelled down in Pliocene. This old erosion surface was described many times in the past but it seems to have been forgotten

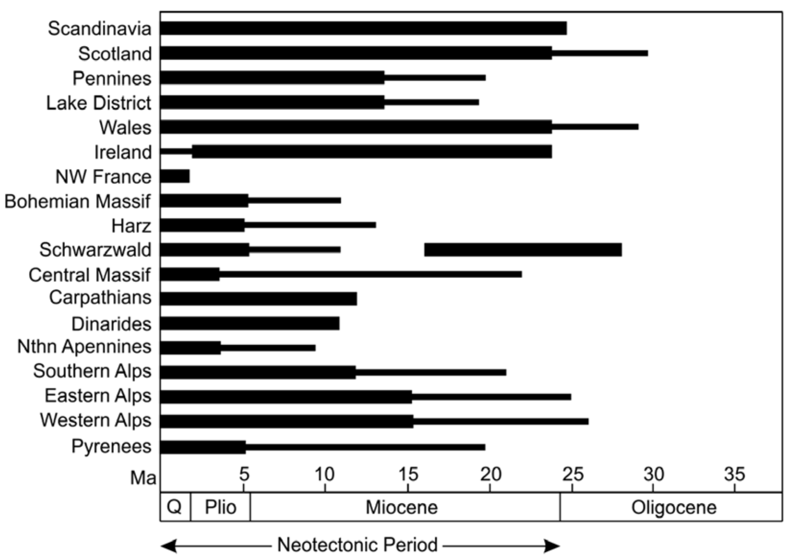

Fig. 1. Large scale uplift in northern and central Europe during the Cenozoic. The line-thicknesses mark regional uplift with high uplift rates (thick) and low uplift rates (thin). Modified from Becker (1993)

Рис. 1. Скорости региональных тектонических поднятий в северной и центральной Европе в кайнозое (по Becker, 1993, с изменениями). Толстые линии показывают высокие скорости поднятий, тонкие — низкие

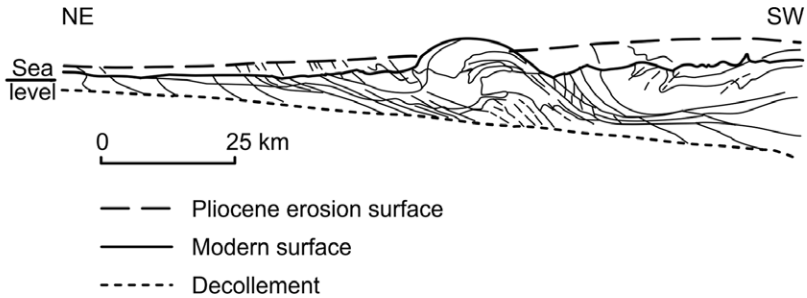

Fig. 2. Cross-section of the Alps. The complicated nappe structures were planated before the uplift of the present mountain mass (simplified after Spencer, 1965)

Рис. 2. Поперечный профиль через Альпы. Сложные шарьяжные структуры подверглись выравниванию еще до поднятия современных гор (по Spencer, 1965, с упрощениями)

in the many plate tectonic explanations of recent years. According to Trumpy (1980) the climax of 'orogeny' occurred in the Eocene but by the Pliocene the Alpine region was worn down to a chain of low hills. Later irregular erosion reduced the Pliocene Plateau to a Gipfelflur, roughly accordant summit heights suggesting a former continuous surface (Rutten, 1969).

More recent work on Alpine regions continues to confirm the story (e.g. Wittmann et al. 2007). De Graaff (2006), Wagner et al. (2010) confirm young uplift for the eastern part of the Alps. Plate tectonic models applied to the Alps totally ignore the planation, so do not explain why uplift occurred so long after presumed collision. Mey et al. (2016) attribute most uplift since the last glacial maximum to isostatic rebound following removal of the Alpine ice cap.

There are other European examples. The mountains of south Bulgaria exhibit Neotectonic uplift after an earlier phase of planation (Ollier, 2006a; Zagorchev, 1992, 2002). The area has a complex horst and graben structure. It was reduced to a peneplain by the Middle Miocene, and during extension in Mio-Pliocene times vertical movements displaced the peneplain by up to 3.5 km. The major movement was in the latest Pliocene.

The Caucasus mountains, between the Black Sea and the Caspian Sea, consist of the Great Caucasus and the Lesser Caucasus with a lowland trough between. The volcanic Mount Elbrus is the highest mountain in Europe at 5633 m. The axis of the Great Caucasus shows the greatest neotectonic activity, with Neogene and Quaternary uplift of about 4500 m. Planation surfaces are well developed on the watershed ridges of both the Greater and Lesser Caucasus. They often consist of accordant summits bevels, in the highlands, and well-preserved erosion surfaces are found at lower levels in the foothills of the Greate Caucasus. These surfaces have gravels that can be correlated and dated, and are Plio-Pleistocene.

Around Mt Elbrus, remnants of planation surfaces have weathered mantles, covered in some places by Upper Pliocene volcanic rocks. The surface and weathering must therefore be not younger than Upper Pliocene, but could be as old as Miocene. In the southeast Caucasus the high surface at 4000–4200 m has been dated as Miocene by correlative sediments. In the eastern end of the Lower Caucasus weathered mantles and marine sediments of Miocene age have been described.

Uplift of the Caucasus region started in the Palaeogene when a narrow ridge emerged from the sea — the precursor of the Great Caucasus. By the Oligocene there was a low mountain system, but most of the Great Caucasus and all the Lower Caucasus consisted of erosional lowlands with some flat areas of deposition. The mountains continued to grow in the upper Miocene and lower Pliocene. Volcanic activity gave rise to lava plateaus and volcanic mountains in central Armenia and south Georgia. Dissection began in the middle Pliocene, but rapid uplift and intense erosion was in the upper Pliocene when the relief of the region took the form that we know today.

The boundary of Europe and Asia is conventionally taken to be along the north-south range of the Ural Mountains, which runs for 3000 km from the Arctic Ocean to the Aral Sea in central Asia. The range has an average altitude of 1000–1300 m, with a highest point of 1894 m.

The Urals have a basement of folded rocks with Precambrian cores in places. This basement is broken up into fault blocks, and fault scarps bound the Urals on both sides. The main structural forms are elongated and divided by parallel deep-seated faults. According to Bashenina (1984) there are also transverse faults that divide the Urals into seven units, each with its own typical pattern of relief.

The Mesozoic and Palaeogene were characterised by prolonged tectonic stability and extensive areas were worn down to surfaces of low relief. The northern Urals were planed down in the Upper Oligocene, when relief was low and elevations up to 500 m. They are now up to 1000 m, reflecting younger vertical movements.

In the Polyarny and Zapolyarny Urals, neotectonic movements commenced close to the Pliocene-Pleistocene boundary. Again, the basic reference is the planation surface evolving up to the late Tertiary, which became modified by differential tectonic movements and denudation into a slightly dissected upland. Further intense movement took place in the Middle Pleistocene, indicated by the appearance of coarse sediments of this age in the foothills.

On the western slopes of the northern Urals five river terraces can be distinguished. The ages are probably Lower Pliocene, Middle Pliocene, Upper Pliocene, Middle Pleistocene, and Upper Pleistocene.

The Transbaikal Mountains

'East of Lake Baikal the remnants of a summit plateau were disrupted by mid- and late-Tertiary block-faulting into a series of northeast southwest trending horst and graben features'. (Bridges, 1990). Lake Baikal itself lies in a half-graben, with a huge fault on the western side and a down-tilted land surface on the east. The westerly fault scarp remains fresh-looking, but is dissected into triangular facets by many valleys draining into the lake. Ufimtsev (1990) described the geomorphology and tectonics, and produced many diagrams showing the faults and erosion surfaces of the region, such as that shown in Fig. 3.

East of the Transbaikal Mountains are the Sayan Mountains, which also were eroded to a peneplain during the Tertiary and uplifted in the late Tertiary. West of the Transbaikal Mountains are the Stanovoy Ranges which make the great divide between drainage to the Arctic and drainage to the Pacific, and north of this is the Aldan Plateau, about 1000 m above sea level, and described as a warped erosional plain (Bridges, 1990). Ufimtsev (1994) describes most of the Mongolian-Siberian region in terms of a warped and faulted planation surface. Most of the rift basins seem to have been initiated during the Late Miocene or Pliocene (Petit and Deverchere, 2006).

The Tibet Plateau, the Himalayas and the Kunlun Mountains

Gansser (1991) wrote: "... we must realise that the morphogenic phase is not only restricted to the Himalayas but involves the whole Tibetan block. This surprising fact shows that an area of 2500000 km^2 has been uplifted 3000–4000 m during Pleistocene time and that this uplift is still

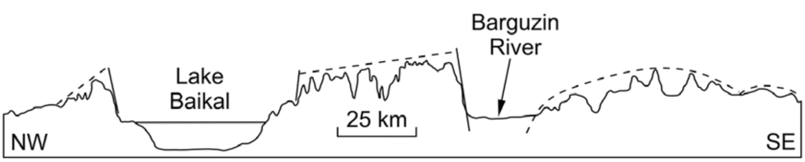

Fig. 3. Diagrammatic cross section across Lake Baikal, showing the warped and faulted planation surface (after Ufimtsev, 1990)

Рис. 3. Схематические поперечные профили через озеро Байкал, показывающие деформированные и разбитые разломами поверхности выравнивания (по Ufimtsev, 1990)

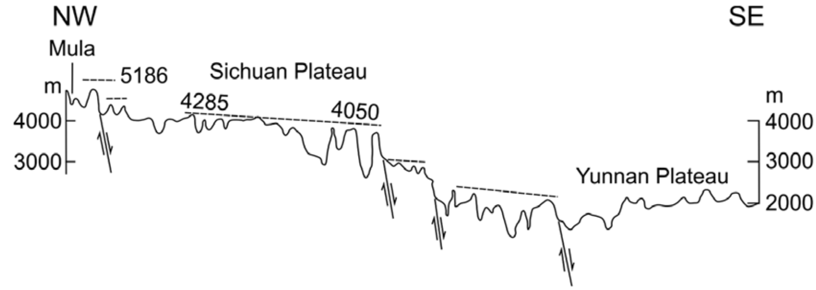

Fig. 4. Profile from the Tibet Plateau to the Yunnan Plateau. A once-continuous plateau, correlated by fossil fauna and flora, was broken up by steep normal faults to form multiple plateaus with total displacement of over 3000 m (after Gao, 1998)

Рис. 4. Профиль от Тибетского плато к плато Юньнань. Некогда единое, согласно находкам ископаемой флоры и фауны, плато было разбито крутыми сбросами на многочисленные ступени с общей амплитудой смещения более 3000 м (по Gao, 1998)

going on". In places the uplift rate is 4.5 mm/year (five times the maximum in the European Alps). According to Wu et al. (2001) from the Pliocene to the Early Quaternary (5–1.1 Ma) the Kunlun Pass area of the Tibetan Plateau was no more than 1500 m high and was warm and humid. They write: "The extreme geomorphic changes in the Kunlun Pass area reflect an abrupt uplift of the Tibet Plateau during the Early and Middle Pleistocene. The Kunlun-Yellow River tectonic movement occurred 1.1–0.6 Ma". Zheng et al. (2000) concluded from sediments at the foot of the Kunlun Mountains that uplift began around 4.5 Ma.

Japanese workers studying the Siwalik deposits in a sedimentary basin filled with erosion products from the Himalayas found that fine sediments give way to a boulder conglomerate at about 1 Ma, indicating a time of major uplift (Prof. T. Kosaka, pers. comm.).

The strongest uplift of the Tibet Plateau and its bordering mountains, the so-called Qinzang (Tibet) movement, occurred in three phases between 3.6 and 1.7 Ma (Li, 1995).

According to Gao (1998) there was one vast plateau over much of Asia, which has been divided by normal faults into several great plateaus that may be correlated by plant and animal fossils (Fig. 4).

Japanese mountains

Island arcs are typical areas for mountain formation according to plate tectonics, where approaching ocean plates compress continental margins to form fold mountains. The Japanese mountains provide a classical example (see many articles in the journal Island Arc). The plate tectonic exponents accept that the major relief and structural framework of the arc-trench system of Japan was formed during the latest Cenozoic, particularly in the Quaternary (Otuka, 1933; Sugimura and Uyeda, 1973) but they usually ignore the widespread planation surface. The Kitakami Mountains of northeast Honshu are said to be typical of the Japanese Islands (Hoshino, 1998). The summit is marked by a peneplain that was formed in the Late Miocene, and the gently inclined flanks of the range comprise an erosion surface with gravel beds that developed in the Late Pliocene. Uplift of the Kitakami Mountains took place during the Pliocene to Early Pleistocene (Chinzei, 1966). The raised peneplain, which makes the skyline of the mountains, is 1000 m in the north and falls gradually to 500 m to the south. The peneplain is also very evident in Southern Japan (Fig. 5). The conventional plate tectonic explanation of Japan as an island arc created by subduction completely ignores the very obvious planation and vertical uplift.

Hoshino (1998) believes the gravels that cap the southern part of the peneplain are of Late Pliocene (Villafranchian) age, and are terrestrial but were deposited very close to sea level.

Fig. 5. The peneplained surface of southern Japan (photo Takao Yano)

Рис. 5. Пенепленизированная поверхность южной Японии (фото Takao Yano)

Timor

Timor is part of an island arc where the mountains are almost 3000 m high. At the end of Neogene folding, the nappe sequence was still deep under the ocean (Audley-Charles, 1986). Since then vertical movement has raised the mountains, and their carapace of stepped coral reefs. According to De Smet et al. (1990) the uplift occurred in two main phases: rapid uplift of 750 m from about 2.2 to 2.0 Ma, with emergence of parts of northern Timor; then, after a quiet period, a second period of rapid uplift starting 0.2 Ma ago that is still active. Rates of uplift vary from 5 to 10 mm/yr. Further north on Buton, Fortuin et al. (1990) report uplift rates of up to 120 cm/ka from the late Pliocene (see also Nguyen et al., 2013).

Papua New Guinea

The Finisterre Range, PNG, was uplifted in the past 4 Ma, and mostly in the past 2 Ma (Abbott et al., 1997). Marls with datable fossils cap most of the plateau. Modern elevations are about 2500 m and this is roughly the amount of uplift in the last one to two million years. Elsewhere in PNG Miocene and Pliocene marine sediments commonly lie at elevations over 3000 m.

New Zealand

"There is clear evidence in New Zealand that mountains (other than volcanoes) have resulted from the uplift of a previously eroded landmass veneered by young Tertiary sediments. Vestiges of the old landmass, which was planated to near sea level in the late Cretaceous and in some places trimmed again in the mid-Tertiary, are often evident in the landscape as exhumed surfaces revealed by stripping of the Cenozoic cover beds. In these places the mountain ranges can be seen to be uplifted fault blocks, commonly tilted, sometimes warped, and always deeply dissected by valleys that have developed in the late Tertiary and Quaternary" (Williams, 2004).

The Rocky Mountains and Related Mountain Ranges

In Western North America there are many uplifted blocks loosely called the Rocky Mountains. Most are related to uplift of blocks or diapirs of Precambrian rock that pushed up overlying strata which often spread or slid off the rising dome. Eardley (1963) pointed out that the largest uplifts droop over surrounding basins and so are gravitational, not compressional. The name 'Rocky Mountains' is misleading, because they consist essentially of several dissected plateaus, with 'ranges' at the edges. The Southern Rocky Mountains Plateau, for example, is

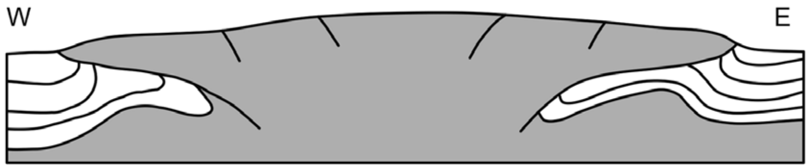

Fig. 6. Diagrammatic section of 'mushroom tectonics' as applied to the Rockies in Colorado. Front Range to the east, Park Range to the west. Precambrian rocks (shaded) spread over younger rocks on both sides (after Jacob, 1983). The approximate distance from Park Range to Front Range is 100 km

Рис. 6. Принципиальное строение массива "грибовидной тектоники" на примере Скалистых гор в Колорадо: на востоке — Передовой хребет, на западе — хребет Парк. Докембрийские породы (серый цвет) налегают на более молодые породы с обеих сторон (по Jacob, 1983). Расстояние между хребтами — около 200 км

bounded by the Front Range on the east and the Park Range on the west. The Front Range is overthrust to the east, the Park Range to the west. The situation suggests original vertical faults that spread under gravity, as so-called 'mushroom tectonics' (Fig. 6).

Foose (1973) gave an excellent summary of the bi-causal pattern of tectonism in the Rockies.

"Throughout the Middle Rocky Mountains a tectonic style may be observed that emphasises the role of two major forces that acted on the crust during the Laramide orogeny [...]. The primary and earliest force was that of vertical tectonism [...]. The secondary force [...] was that of gravity, which extensively remodelled the basically simple geometry of the initial blocks in the Middle Rocky Mountains by creating a variety of structural features that provided for the release of stress within the blocks. Release of stress was accompanied by movements of parts of the block along the newly created structures in directions outward and downward toward the adjacent basins".

Planation surfaces are widespread in the Rockies, though ignored by later, plate-tectonic, interpretations. Loomis (1937) wrote "The Northern Rocky Mountain Province is a complex of many ranges that have been revealed by dissection of a peneplain which can be traced over the whole area". Atwood (1940) wrote "Many persons who have studied the Front Range of Colorado have called the remnants of this old-age erosion surface in that section the Rocky Mountains Peneplain". He lists many other plateaus in the area such as the Green Ridge Peneplain and the Medicine Bow Peneplain. The age of the Rocky Mountain planation surface varies from place to place. In Central Colorado it is demonstrably Late Eocene, but in much of the Laramide and Medicine Bow mountains it is Miocene.

There are many drainage anomalies in the Rockies, where rivers go through the mountains, not around them, indicating antecedent drainage: the river courses existed before uplift (Ollier and Pain, 2000, p. 103). The fault blocks are elongated, and run in many directions from E-W (Uinta Dome), NW-SE (Owl Creek, Wind River), to N-S (Front Range). This, together with the divergent thrusts away from the centre of the blocks, makes it difficult to accept plate tectonic explanations of subduction-related uplift.

Mountains on passive continental margins — Great Escarpments

The popular image of a mountain range is a rather tent-like ridge of high ground, but as shown in Fig. 7 many of the mountain 'ranges' of passive margins are Great Escarpments, including such eminent ranges as the Western Ghats of India, the Drakensberg of South Africa and the Blue Mountains of Australia.

We discuss mountains on passive continental margins separately because they differ from others in several respects (Ollier, 2004), though they are similarly created by erosion of a plateau (Fig. 7). They may have been originally high, like the high plateaus bounding many present-day rift valleys, or uplifted at the time new continental margins were formed. Ollier and Pain (1997) suggest that the plateau surface may be equated with the break-up unconformity beneath

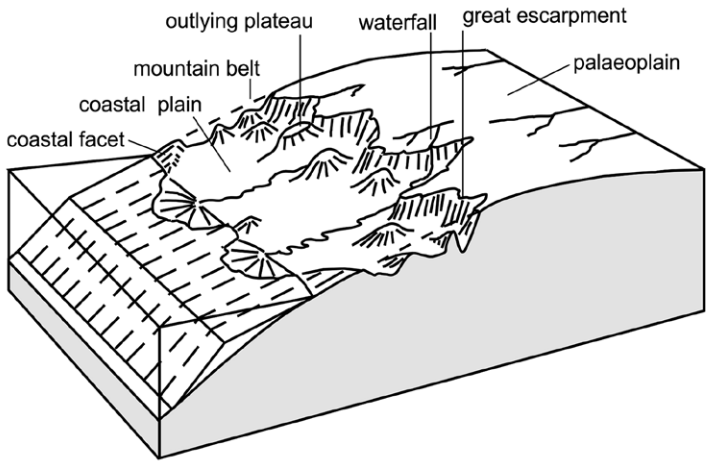

Fig. 7. The basic geomorphology of passive margins with mountains

Рис. 7. Основные геоморфологические единицы горных пассивных окраин материков

marine sediments offshore. In this situation offshore sediments may be used to determine time or times of uplift. Most passive margins appear to have two periods of movement, one around the time of creation of the new continental margin, and a later one in the Neotectonic Period (Ollier, 2004). Space does not permit discussion of all the items listed in Table, but the following are some examples.

The Scandinavian margin had continuous uplift from the Mesozoic, but in Southern Norway there was renewed uplift of about 1000 m in Neogene time (Lidmar-Bergström et al., 2000; Lidmar-Bergström and Näslund, 2002).

Partridge (1998) has Mesozoic precursors for the South African high plains landscape, and also Pliocene uplift of up to 800 m. He wrote: “The evidence for large-scale Neogene uplift is now beyond question”.

In Australia the eastern highlands are associated with a palaeoplain of Trias-Jura age (Hills, 1975). Uplift was attributed once to the Plio-Pleistocene ‘Kosciusko Orogeny’ (Andrews, 1910). This idea was replaced by general belief in Early Cenozoic uplift, but some movements of up to 1 km may have occurred in the Pleistocene (Ollier and Taylor, 1988).

In Western India Widdowson and Gunnell (1999) showed several phases of laterite formation on the coastal plain. The elevation of the coastal laterite (up to 200 m) together with associated development of an entrenched drainage indicates that widespread uplift has affected the margin during Late Tertiary times.

In the Appalachians the palaeoplain (Schooley peneplain) might date back to the Cretaceous but there is also evidence of Miocene or younger uplift, especially in the Piedmont province (Pazzaglia and Gardner, 2000; Stanford et al., 2001).

In Greenland the highest and oldest planation surface cuts across Late Miocene basalt, so uplift is later than that (Weidick, 1976).

The Transantarctic Mountains may have experienced major uplift since the Early or Middle Pleistocene (Behrendt and Cooper, 1991), or may have remained at their present level since the Miocene (Kerr et al., 2000).

DISCUSSION

Terminology and the nature of mountain uplift

This section is an aside from the main theme of Neotectonic uplift, but in explaining mountain building we have to avoid some terminological traps.

Our ideas on the origin of mountains affect even the very language that we use to describe mountains. Early ideas based on a cooling, shrinking Earth, with mountains formed like wrinkles on a shrinking apple still influence modern thinking, including the idea that folds (and mountains) are formed by compression as the crust adjust to fit a smaller Earth.

The term 'orogeny' literally means the genesis of mountains, and when proposed it meant just that. In later years the idea that folding and mountain building were the same thing became entrenched, and eventually the term orogeny came to mean the folding of rocks. Orogeny is now used to refer to the folding of rocks in fold belts and no longer means mountain building. Burg and Ford (1997) claim that "To field geologists the term orogeny represents a penetrative deformation of the Earth's crust". Unfortunately not all geologists are agreed on this, which leads to much confusion.

The nearest thing to an official definition is that of the American Geosciences Institute *Glossary of Geology* (Neuendorf et al. 2011):

"... orogeny literally, the process of formation of mountains. The term came into use in the middle of the 19th century, when the process was thought to include both the deformation of rocks within the mountains, and the creation of the mountainous topography. Only much later was it realised that the two processes were mostly not closely related, either in origin or in time. Today, most geologists regard the formation of mountainous topography as postorogenic. By present geological usage, orogeny is the process by which structures within fold-belt mountainous areas were formed, including thrusting, folding, and faulting in the outer and higher layers, and plastic folding, metamorphism, and plutonism in the inner and deeper layers. Only in the very youngest, Late Cenozoic mountains is there any evident causal relationship between rock structure and surface landscape. Little such evidence is available for the Early Cenozoic, still less for the Mesozoic and Paleozoic, and virtually none for the Precambrian yet all the deformation structures are much alike, whatever their age, and are appropriately considered as products of orogeny".

In contrast to orogeny, early geologists used epeirogeny to mean the uplift of broad areas, as opposed to the narrow fold belts of mountain chains. Stille (1936) expressed it thus:

"As a matter of fact, orogeny in the tectonic sense generally fails as an explanation for the existence of the topographically great mountains of the Earth, such as the Alps of Europe or the Cordilleras of North America. These mountains exist — or still exist — as a result of post-orogenic en bloc movements, for the most part still going on, and belonging to the category of epeirogenic processes. Thus arises the terminological contradiction, that the mountains as we see them today owe their origin not to what is called orogeny, but to an entirely different type of movement that is to be strongly contrasted with the orogenic process".

Nevertheless orogeny is still equated with mountain building by many geologists. We stress that Neotectonic mountain building was caused by vertical uplift, with no necessary relation to compression or folding.

Many books on mountain-building and orogeny are confused about the origin of mountains and the origin of structures inside them. Hsü's '*Mountain Building Processes*' (1982) is all about structures and it is simply assumed by most contributors that 'orogeny' creates both internal structures and the present-day topographic mountains. Only Gansser (1991), in his chapter on the 'morphogenetic phase' of mountain building, distinguishing the late, vertical mountain building from earlier (assumed) compression. Schaer and Rogers' book '*The Anatomy of Mountain Ranges*' (1987) is likewise about internal structures, tacitly assumed to be related to present day mountains. Orogeny is still equated with mountain building by many geologists.

The relationships of mountains to folding and compression

Because of the widespread assumption that folding and mountain building are the same thing, it is necessary to stress that folding and mountain uplift are quite different things. Both mountains and lowland plains can be underlain by folded or non-folded rocks. When folded rocks are found under a lowland plain nobody assumes the folding caused the plain! Why should such a causal relationship be assumed with mountains? Fig. 8 provides a summary of possible relationships:

	FOLDED ROCKS	HORIZONTAL STRATA	HORIZONTAL BASALT	GRANITES	METAMORPHIC ROCK
MOUNTAINS	Alps	Drakensberg	Snake River	Sierra Nevada	Scottish Highlands
PLAINS	Amazon Basin	Murray Basin	W. Victoria Plains	Western Australia	Finland

Fig. 8. The relationship between mountains, plains and geological structure. There is no simple relationship between mountains and folding, or any other structure

Рис. 8. Взаимоотношения между горами, равнинами и геологической структурой. Не существует прямых связей между горами и складчатостью или любым другим типом геологических структур

Clearly there is a need to divorce mountain building from folding. Furthermore, in areas that are underlain by folded rocks there is usually a period of erosion to produce a planation surface before the vertical uplift that forms the mountains. Since the days of the Shrinking Earth it has been assumed by many that both folds and mountains are caused by compression. Folds are indeed formed by local compression, but it need not be crustal compression. Gravity sliding can create folds (and thrust faults and nappes), and the Niger Delta, still under the ocean, replicates many of the features seen in section of mountains such as the Apennines and Alps (Fazlikhani et al., 2017).

Gravity slides can also occur after uplift of tectonic blocks, as in some of the Rocky Mountains (Fig. 9). Gravity spreading can also lead to folding, with divergent folds on opposite sides of an uplifted block: for examples see Ollier and Pain, 2000, Chapter 8. Distinguishing features of pre-and post-uplift building folding have been described by Ollier (2002). Gravity sliding has long been championed by European geologists such as van Bemmelen (1975), de Sitter (1952), Rutten (1969) and papers in De Jong and Sholten (1973).

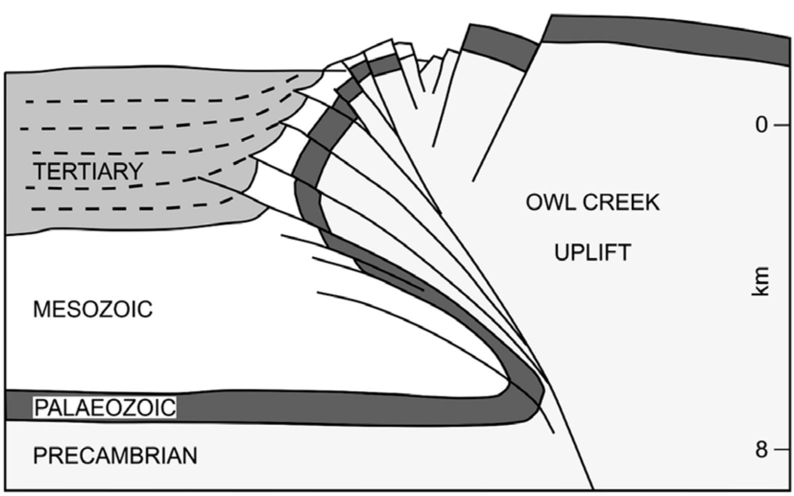

Fig. 9. Suggested structure of the frontal zone of Owl Creek uplift, Wyoming (after Wise, 1963). No vertical exaggeration

Рис. 9. Предположительное строение фронтальной зоны поднятия Оул Крик, Вайоминг (по Wise, 1963). Вертикальный масштаб равен горизонтальному

It should also be stressed that mountains can occur in a non-compressional, tensional regime. The most renowned is probably the Basin and Range Province of the Western USA. This region has extended by hundreds of kilometres since the Eocene (Elston, 1978), and Long (2018) reports 230±42 km of cumulative extension in the same area. The Ruwenzori Mountains of central Africa border the Western Rift Valley, an area of tension and the Baikal Mountains border the tensional half-graben of Lake Baikal.

Sometimes the situation is even more complicated. The *Glossary of Geology* (Neuendorf et al. 2011) has this observation: massif (mas-sif') A massive topographic and structural feature, especially in an orogenic belt, commonly formed of rocks more rigid than those of its surroundings. These rocks may be protruding bodies of basement rocks, consolidated during earlier orogenies, or younger plutonic bodies. Examples are the crystalline massifs of the Helvetic Alps, whose rocks were deformed mainly during the Hercynian Orogeny, long before the Alpine Orogeny.

Of course we would add that the Alpine Orogeny only folded the rocks: the uplift that made the topographic mountains came later, in the Neotectonic Period.

In brief, there are no 'fold mountains'. When folded rocks underlie mountains the folding pre-dates planation and uplift. The one exception is post-uplift gravity spreading of very large fault blocks.

Time and periodicity of uplift

A topic of long-standing debate in geology is whether there are distinct mountain-building periods or whether the process might be continuous through Earth history. Shepard (1923) for example, argued that mountain building must be continuous because shrinkage of the Earth was continuous.

The conclusion reached in the present paper suggests that at least the latest orogeny was roughly synchronous over a large area of the world. However, there is no doubt that some uplift was at different times. Passive margin uplift is frequently older, possibly going back to the early Tertiary, and some may be older still. Some, like the Scandinavian warp, seems to have a resurgent action on the same site even since the Mesozoic. Nevertheless there does seem to have been a major pulse of uplift in the Pliocene extending into the Pleistocene and even the present day. In some instances this uplift was preceded by folding (Apennines, New Guinea), but in many other places it was not. Uplift of many mountains was synchronous: orogeny (in the sense of folding of rocks) was not. The folding of the Caledonian rocks of Scandinavia and Scotland is much older than the uplift that made the mountains. The structures in the Carpathians are much older than the late Pliocene uplift.

Uplift occurred over a relatively short and distinct time. Some unknown process switched on and created mountains after a period with little or no significant uplift. We are seeing the results of a distinct and remarkably young mountain building period. This is a deviation from strict uniformitarianism. It also implies that the geomorphology of today might be rather special.

The relatively short mountain building period is not on the same time scale as granite intrusion (which takes tens of millions of years), or plate tectonics which is supposedly continuous over hundreds of millions of years. The same rapid uplift occurs in areas where hypotheses such as mantle plumes do not seem appropriate. We do not yet know what causes this short, sharp period of uplift, but at least the abandonment of naive mountain-building hypotheses might lead to more realistic explanations.

For the past fifty years plate tectonics has dominated geology, and the greatest single theme has been subduction, which allegedly formed both mountains and the structures within them. Subduction may have a role in other studies, but because it is a continuous process that has allegedly operated for hundreds of millions of years, it is a most improbable mechanism to make mountains in a few million years, complete with their erosion surfaces. In areas of Plio-Pleistocene uplift there is no time for subduction to be an effective mechanism.

Most of the Plio-Pleistocene mountains are parts of what is generally referred to as the Alpine orogeny. The Andes, the Tibet Plateau and Himalayas, and the European Alps themselves are all classic examples. A few other mountain areas not regarded as 'Alpine' also have planation surfaces uplifted in the Pleistocene, such as the Urals, Ruwenzori, the ranges of central Spain, and those of Central Asia. The 'Alpine Orogeny' seems to be a real thing, in the sense of mountain building as well as 'the formation of folds and rock structures'. What has become clear in this paper is that most of the rock structures such as folds and faults were formed before the vertical uplift that actually formed the mountains.

Mountain building and climate change

The formation of mountains affects climate at local, regional and global scales. Simple elevation produces lower temperatures, induces orographic precipitation, produces rain shadows, and affects wind circulation. Changing topography changes climate.

The Sierra Nevada is a tilted fault-block mountain range, and climate change was used to work out its age: it is a classic of Neotectonic studies. At present the western side is humid, the high parts alpine and the eastern side is very arid, not far from Death Valley. In the Early Pleistocene similar vegetation covered the whole region, a situation that could only exist if the present climatic barriers were absent, so the major uplift is well into the Pleistocene (Axelrod, 1962).

The Quaternary uplift of the Tibet Plateau and the Himalayas introduced a powerful new geographical factor in the pattern of world climate. Uplift of the Himalayan Range to its present 6000 m average elevation made it an effective climatic barrier, preventing warm, moist air from entering the Tibetan Plateau. Possibly the upheaval of the plateau created the monsoons of East and South Asia (Manabe and Terpstra, 1974). The monsoon links the low pressure cell over the Tibet Plateau (India Low) to both the Pacific High and the Australia High, leading to inter-hemispheric temperature exchange, and so plays a part in global climate changes (Liu and Ding, 1998).

The coincidence in time between plateau uplift and late Cenozoic glaciation suggests that the mountain building may control major aspects of climate. The cause of the general cooling of the late Cenozoic Ice Age could be uplift of land masses. Cycles such as the Milankovich cycle control some of the details, but the cause of the general cooling of the late Cenozoic Ice Age could be uplift of land masses.

Molnar (2007), who thinks all geologists who describe Neotectonic uplift are wrong (as described later) wrote: "Global climate change offers the only globally synchronous process that could mislead so many geologists to infer a recent rise of high terrain".

Theories of geomorphology

The Neotectonic Period does not fit easily into major theories of geomorphology and especially cyclical theories.

Davisian geomorphology depends on a relatively rapid uplift initiating a new cycle of erosion. This should give rise to a series of peneplains, or perhaps just one peneplain modified by later erosion. For instance, in his best illustrative example the Schooley Peneplain was uplifted to form the bevelled cuestas of the Appalachians, dissected by later rivers. In his day argument was over whether other 'partial peneplains' could be detected. Here we are concerned only with the uplift of the main peneplain. But in the Neotectonic period we might initiate several cycles in the last few million years in active areas. We know many planation surfaces are much older, but their uplift and preservation do not fit readily into a cycle. We must remember that Davis evolved his ideas long before continental drift, with formation of new continental margins, was accepted, let alone the complex ideas of plate tectonics. Belief in a fixist Earth did not allow the creation of new continental margins. Davis simply created new base levels by vertical uplift.

Lester King's idea of global planation surfaces was, like Davis's theory, a cyclical theory. The main difference was in the proposed mechanism of pediplanation — backwearing rather than downwearing. Both Davis and King believed epeirogenic uplift led to initiation of a new cycle (King coined the redundant word cymatogeny for epeirogeny). This still appears true, and the Neotectonic uplift often affected broad areas, though there are other places where uplift is more localised, as in the horsts of the Rocky Mountain region. Downward movement forming rifts and graben is also associated with the Neotectonic Period, and together with uplift caused many changes of base level. The bedrock bases of some rift valleys are well below sea level.

King accepted continental drift, and had the formation of new continental margins as another way to initiate new planation surfaces. But despite his acceptance of unorthodox tectonic models, King did not specifically relate formation of new surfaces to a newly formed continental margin. It would not have been possible in fact, because a new continental margin could only produce one new base level and planation surface, but King had five. King attempted to correlate planation surfaces around the world. Yet all but the youngest, present cycle were older than the Neotectonic Period. The oldest surface was the Gondwana Surface, presumed to be the basic surface before continental break-up.

We shall not discuss other general theories such as Penck's treppen concept, or climatic geomorphology, but it should be clear that they have problems with Neotectonics.

Mountains and Plate Tectonics

For the past fifty years plate tectonics has dominated geology, and the greatest single theme has been subduction, which amongst other things allegedly formed mountains and also the structures within them. Subduction may have a role in other studies, but because it is a continuous process that has allegedly operated for hundreds of millions of years, it is a most improbable mechanism to make mountains in a few million years, complete with their erosion surfaces. In areas of Plio-Pleistocene mountains there is no time for subduction to be an effective mechanism.

The plate tectonic hypothesis of mountain building depends entirely on subduction at 'active' continental margins and island arcs. Such subduction is presumed to bring compression, causing both the folding of rocks and the uplift of mountains. But mountains are not confined to 'active' margins and are found on passive margins and in continental interiors.

Owen (2004), writing of the plate tectonic origin of mountains, noted that besides the Alpine-Himalayan and Circum-Pacific mountains there are "... regionally extensive and significant mountain belts of lesser relief. These 'ancient' mountain systems generally have little or no relationship to the present lithospheric plate boundaries and may have begun to have formed many hundreds of millions of years ago. Despite their age and distance from plate margins these mountain systems may still experience deformation, albeit not so dramatic as young active mountain belts". The use of 'ancient', aimed at deflecting attention from these 'anomalous' mountains, does not match the details of their age as shown in Table.

Molnar (2007) recognized that young and universal mountain uplift was not consistent with plate tectonics, and launched a severe attack on Neotectonics. He wrote "For virtually every mountain belt and high plateau, as well as for many topographically minor features, a credible, if not outstanding, geologist has asserted that that high terrain rose abruptly in Pliocene and/or Quaternary time." But later "... although not all inferences of recent increases in mean elevations (or whatever has been meant by the word "uplift") need be false, most surely are". Why does he think so many get it wrong? Because "The lack of a globally synchronous change in rates of plate motion in the past few million years denies any suggestion of a globally synchronous, coordinated rise of high terrain a sensible tectonic cause". In other words, because the Neotectonic Period is incompatible with plate tectonics it must be wrong.

Molnar (2007) notes that "Harold Jeffreys, one of the Twentieth Century's two or three most outstanding earth scientists, argued that continental drift did not occur because it could not occur" (p. 395). Although aware of Jeffreys' "misguided path", Molnar (2007) states that "a simultaneous uplift of mountain ranges throughout the earth and beginning at 2–4 Ma cannot have occurred and, therefore, did not occur" (p. 404). The parallel is obvious.

The breathtaking arrogance that all the 'credible if not outstanding' geologists are wrong and Molnar is right is astonishing, at first sight. But in fact Molnar is taking a stand for the entire Plate Tectonics camp and is stating the presumed view of all its followers, who comprise a vast majority of geologists in the world today.

The number of examples of Neotectonic uplift listed here is much larger than the list used by Molnar, and we do not believe so many eminent geologists are mistaken. The fundamental cause of uplift is beyond the scope of the present paper, and we are content for now to maintain that it is a thoroughly documented fact.

Plate tectonic theory pervades papers of the past 50 years, the theory far outdistancing observation. It is necessary to go to older literature to get an adequate description of geology and geomorphology that has not been twisted to fit the plate tectonic model. Early observers noted what they saw, while many later writers felt they had to fit in with the rules of plate tectonics, and modified not only the ideas but also, in some instances, the facts. This is an unfortunate consequence of excessive orthodoxy. As Claude Bernard expressed it:

"Men who have excessive faith in their theories or ideas are not only ill-prepared for making discoveries; they also make poor observations".

We must distinguish between truth, which is objective and absolute, and certainty, which is subjective (Popper).

CONCLUSIONS

Mountains are created by the vertical uplift of former plains, independent of any folding of the rocks underneath. The age of mountains should therefore refer to the age of vertical uplift after planation, not to the last period of folding (if the underlying bedrock happens to be folded). Most mountains were uplifted in the Neotectonic Period in the Plio-Pleistocene, or the very Late Miocene. The Neotectonic Period is demonstrated by the large amount of work, a small sample of which is listed in Table, and we note that similar work continues to be published (e.g. Alves et al., 2019).

Plate tectonics, the ruling theory of the past fifty years, has no adequate explanation for the widespread planation in mountain regions, or the remarkably young uplift. Indeed it is based on an association of folding and uplift that is demonstrably untrue. Moreover, plate tectonics has no plausible explanation for mountains on passive margins or continental interiors. Any hypothesis of mountain building should incorporate the formation of planation surfaces, and explain the uplift of mountains in a few million years.

The ultimate cause of uplift is still unknown, but the proven existence of the Neotectonic Period puts clear limits to speculation about causes. Geomorphology, along with stratigraphy, palaeontology and other branches of science, has the opportunity to elucidate the story of mountain uplift, or at least constrain models derived from theory and modelling.

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