Landslide Research and Technology in Patent Documents

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Abstract

Science, Technology, and Innovation play a crucial role in the Sendai Framework for Disaster Risk Reduction 2015–2030 (SF DRR). The International Consortium on Landslides (ICL) initiated the Sendai Landslide Partnerships 2015–2025 as a voluntary commitment to SF DRR. In 2020, the ICL launched the Kyoto 2020 Commitment for Global Promotion of Understanding and Reducing Landslide Disaster Risk (KLC 2020) as a follow-up of the Sendai Landslide Partnerships 2015–2025. Closely related to the above-mentioned Innovation are patents as a form of intellectual property rights and are often used as an innovation assessment parameter. This article reports on a study conducted to look at the patent documents that are available in open-access databases in order to evaluate how well they relate to the field of landslide research and technology. Landslide-related patent documents were extracted using different search terms in the patent document titles, abstracts, claims and/or their general text from the Google Patents, using the Espacenet tools from the European Patent Office, and the Derwent Patent Index inside the Web of Science offered by Clarivate Analytics, respectively. The extracted patent documents were analyzed with regard to the applicant respectively inventor affiliation (academic, non-academic, country of affiliation) and to the technical field of a patent using well-known patent classifications. The most active countries claiming landslide-related patents were recognized. Furthermore, review and research articles in SpringerLink and SCOPUS databases were searched to study how often scientific articles are citing landslide-related patents. The results of the study can be summarized as follow: (i) in the Google Patents database there are 15,000 + landslide-related patent documents, and in the Espacenet and the Derwent Innovation index database 5000+, respectively. In the patents titles, abstracts, and claims, processes are more often used to describe the patent than the technology; (ii) the number of technological (non-science) based patents is higher than that of academic (science-based) patents, with some specific field of applications, where the situation is the opposite; (iii) with regard to the different areas of technology to which landslide-related patent documents pertain, the categories "G-Physics" and "E-Fixed constructions" are clearly prevailing: "G" for debris flows and landslides, and "E" for fallings rocks and mudflows; (iv) the majority of landslide-related patents are filled and/or granted in China, followed by Japan and South Korea, USA and EU member countries—five major emerging economies (called BRICS) are outperforming developed countries, with a very prevailing Chinese contribution; (v) only a fraction of the order of a few one-in-thousands of landslide-related patents documents are cited in journal review and research articles.

Keywords

Citations • Innovation • Intellectual property • Landslides • Patents • Technology transfer

1 Introduction

Technological learning and innovation are essential for economic growth and development, and are major determinants of long-term improvements in income and living standards. While in the more advanced economies technological progress involves the generation of new knowledge that can be applied to productive activity, for developing countries technological progress is strongly influenced by their ability to access, adapt and diffuse technological knowledge that has been generated abroad (UNCTAD

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2014). Strengthening the technological capabilities of developing countries will be critical for the achievement of the 2030 Agenda for Sustainable Development (UNCTAD 2019). The status and trends of innovation can be assessed through patent analysis, as was done for India by Abraham and Moitra (2001), or e.g. technological development of a selected technology such as UAV (Unmanned Aerial Vehicle) can be reviewed through patent analysis of its hardware and software as done by Chen et al. (2016).

But technological progress is not only important for economic growth and development, but also plays a role in increasing society resilience against natural disasters. Callaghan (2016) claims that disasters decreasing the number of factors of production would stimulate innovations that will reduce the use of them—technological innovation is therefore of great importance in mitigating climate disasters, including natural disasters.

Science, Technology and Innovation thus play a crucial role in the Sendai Framework for Disaster Risk Reduction 2015–2030 (UNISDR 2015). This is more clearly visible in the Science and Technology Roadmap to Support the Implementation of the Sendai Framework for Disaster Risk Reduction 2015–2030 (UNISDR 2019). Cui et al. (2021) studied scientific challenges of research on natural hazards and disaster risk, with the emphasis on China. As one of the short-termed goals (2021–2025) for China, technology platform construction was named, including policy communication in science and technology innovation. Closely related to innovation are intellectual property rights, among them also patents. Hu et al. (2018) studied the innovative response to climate disasters in modern and historical China. In modern China (investigated period 2005–2013), past climate disasters have led to an increase in the number of disaster-mitigating patents that boost also innovations in other fields. In historical China (investigated period 11 to 1910) climate disaster only spurred innovations in disaster mitigation fields and not in others. They concluded that it is important for policymakers, including governments, to increase investment into research and technological development sectors after climate disaster.

As a widely known example, we may name the Reinforced Earth®, originally invented in 1963 as a method of using composite earth as a supporting structure—until nowadays claiming numerous patent families, trademark and design rights as forms of intellectual property (RECo 2022).

An inventor receives a patent, if (i) the invention is new, (ii) an “inventive” step is recognizable, and (iii) the idea has to be industrially applicable or useful (Ullberg 2020). The patent system grants and enforces temporal exclusive, transferrable, and licensable private rights on inventions—that provide solutions to (mostly) technical problems in the area of products and processes (Ullberg 2020). Patents are an important result of progress in science and technology and related innovation activities—but not all patents are science-based, they can also be non-science-based (Wang and Li 2018). University-owned patents are more related to scientific questions while corporate-owned patents are more connected with direct commercial goals (Sterzi 2013).

Bae et al. (2014) analyzed existing patents related to real-time monitoring and detection technology for landslides on natural terrain. The purpose of patent analysis was to understand landslide hazard technology trends and to develop new advanced technology. The study searched patent data using key words related to landslide monitoring and detection in Korea, the USA, Japan, China (Hong Kong), Europe, and Taiwan. The patents were divided into five main categories and five to seven subcategories in each main category and analyzed by year, country, and applicants. The results were utilized to derive a portfolio of promising technologies for each country.

Jelić (2018) presented systematic overview of patented inventions created in twenty-first century by Serbian scientists and inventors in the field of seismic safety of structures and landslide remediation, as well as examples of their specific application.

The International Consortium on Landslides (ICL) initially launched a book series entitled “ICL Contribution to Landslide Disaster Risk Reduction” (CLDRR; Springer 2022b) to publish integrated research on all aspects of landslides. As decided by the Kyoto 2020 Commitment for Global Promotion of Understanding and Reducing Landslide Disaster Risk (KLC 2020), this book series was in 2022 replaced by an open-access book series entitled “Progress in Landslide Research and Technology” (P-LRT), published by Springer Nature (Sassa 2021b). The book series is one of the ICL main contributions to the KLC 2020 Landslide Commitment. Many signatories of the KLC 2020 Landslide Commitment are active in technology development and technology transfer (Konagai 2021a; 2021b; 2021c; 2021d). This article is well aligned with the title and aims of the new ICL book series, as well as it is a contribution to the KLC 2020 Landslide Commitment activities (Sassa 2021a).

In this study, the focus was given to the field of progress in landslide research and technology as can be evaluated by the wealth of landslide-related patents in freely accessible databases of patent documents, using the basics of patent searching (Clarke 2018).

The following research questions were defined when working for this study:

- what is the number of landslide-related patent documents in diverse databases;
- what is the share of landslide-related patent documents coming from academic institutions, research institutions, ministries or other public bodies, and industry;

- in which technical fields landslide-related inventions are claimed;
- which countries are leaders in patenting landslide technologies;
- how often scientific journals cite landslide-related patent documents?

2 Materials and Methods

2.1 Meaning of the Term "Patent"

When searching in databases or on the web for information related to patents, we should bare in mind that the English word "patent" has several meanings (Lexico 2022):

- patent as noun with synonyms such as copyright, licence, legal protection, right, … or adjective with synonyms such as patented, licensed, protected, … (this meaning is of relevance for this study);
- patent as adjective with synonyms such as obvious, clear, evident, apparent, … (and this is not relevant for this study).

and results of a search must be checked for this difference (for more definitions on the term "patent" you may see (Collins 2022)). Furthermore, some publishers (e.g. Springer Nature) demand that all the authors of a manuscript reveal their potential competing interests among them also whether they held any patents related to the content of published articles. This fact complicates any search for patents in their database (i.e. SpringerLink).

2.2 Patent Documents Databases

There are different search engines available to search for patent documents, among others:

- Espacenet is a free-of-charge patent search engine offered by the European Patent Office (EPO 2022a) that includes 130 + million patent documents from around the world (EPO 2022b).
- Google Patents is a patent search engine created by Google that includes 120 + million patent publications from 100 + patent offices around the world (Google 2022).
- Derwent Innovations Index is a research tool within Web of Science (Clarivate 2022a) with patent information on more than 30 million inventions detailed in over 65 million patent documents from over 50 patent issuing authorities, including information on patent citations.
- Innography PatentScout™ is a private web-based platform (Clarivate 2022c).

The Espacenet database of inventions and technical developments covers the period from 1782 to today. The following definitions are helpful to understand the elements of patent documents (EPO 2022b):

- *Applicant*: A person (i. e. natural person) or an organization (i. e. legal entity) that has filed a patent application. There may be more than one applicant per application.
- *Claims:* Part of a patent application or specification. Defines the technical features for which protection is sought. There are dependent and independent claims. Independent claims contain the main features of the invention. Any independent claim can be followed by one or more dependent claims.
- *Classification:* Patent classification is a system of sorting inventions and their documents into technical fields covering all areas of technology. Espacenet shows the International Patent Classification (IPC, established in 1971; IPC 2022) and the Cooperative Patent Classification (CPC 2022), where available. Every patent document, regardless of whether it is an application or a granted patent, is given one or more classification symbols by an examiner indicating that it is allocated to a specific area of technology.
- *Country codes:* consist of two letters indicating the country or organization where the patent application was filed or granted.
- *Description*: Part of a patent application or specification. Discloses the invention as claimed, specifies the technical field to which the invention relates and indicates any prior art the applicant is aware of.
- *Inventor:* A person designated as an inventor in a patent application. An inventor can also be an applicant. An inventor is always a natural person. There may be more than one inventor per application.
- *Patent family*: Set of interrelated patent applications filed in one or more countries to protect the same or a similar invention by a common inventor and linked by a common priority (or priorities).

In the Google Patents database one can search among patent titles, abstracts, claims, or in all three of them.

In the Derwent Innovations Index one can search among patent titles ("Title"), patent titles and abstracts ("Topic"), inventor names ("Inventor"), patent assignee names ("Assignee") and patent numbers ("Patent Number").

2.3 Patent Classifications

Patent offices worldwide use the International Patent Classification (IPC 2022). There are approximately 70 000 different IPC codes for different technical areas, grouped to classes A to H: A-Human necessities, B-Performing operations; transporting, C-Chemistry; metallurgy, D-Textiles; paper, E-Fixed constructions, F-Mechanical engineering; lighting; heating; weapons; blasting engines or pumps, G-Physics, H-Electricity.

The Cooperative Patent Classification (CPC 2022) is an extension of the IPC and is jointly management by the European Patent Office (EPO) and the US Patent and Trademark Office (USPTO 2022). It is divided into nine sections, A-H (as in IPC) and Y, and there are approximately 250,000 classifications entries (CPC 2022). Not being part of the IPC, the Class Y is for general tagging of new technological developments and cross-sectional technologies. There is available a statistical mapping of the IPC to CPC classification, if needed.

2.4 Patent Documents Citations

Looking at patent documents, a research question whether and to which extent these documents are cited in scientific literature, specifically in the indexed journals that are available in diverse databases. We used SpringerLink and SCOPUS to look at the total number of landslide-related patents cited. To look at the individual review and original research articles citing landslide-related patent documents, we have selected Web of Science (Clarivate 2022b) as a global citation database with almost 1.9 billion cited references from over 171 million records.

3 Results and Discussion

3.1 The Number of Landslide-related Patent Documents

We used a set of over 30 search terms in the three databases (Espacenet, Google Patents, and Derwenta Innovations Index) and the results are shown in Tables 1, 2 and 3. We tried to cover the variety of landslide forms (Hungr et al. 2014), without going into too much detailed description of different forms—mainly the terms "earth", "debris", "falling rock/stone", "landslide", "mudflow", "rock avalanche", and "rockfall" were used. We intentionally did not want to add some typical technological solutions (structural measures), such as "retaining wall" or "drainage", since they have very high number of patent documents (e.g. "retaining wall(s)" with over 100,000 patent documents having this term in their description).

Typically, the largest number of landslide-related patent documents were found when searching in all text fields or description (Espacenet), and less when looking only in the Title or Abstract. For the Google Patents database, the best option was to look at the "Title, Abstract, and Claims"—only Abstracts or Claims can yield too high numbers (i.e. 135,828). For the Derwenta Innovation Index, only Title and Topic was searchable, yielding comparable number of patent documents. Comparing all three databases, the most patent documents are related to "Retaining walls" followed by "Landslide(s)", "Debris flow(s)", "Mudflow(s)", "Rock fall (s)", and "Falling rock(s)". It is clear that more general terms describing processes rather than technology are prevailing—overlooking the search term "Retaining walls" as a geotechnical technique not applicable only in landslide disaster risk reduction. In total, a rough estimation is that in the Google Patents database there is 15,000 + landslide-related patent documents, and in the Espacenet and the Derwent Innovation index database 5000+, respectively.

3.2 Patent Documents, Inventors and Applicants

For the analysis of science and non-science-based landslide-related patents we used only the Espacenet database and the selected 18 search terms in "Claims" (Table 4). The Inventors respectively Applicants were grouped into Academic institutions and Research institutions for science-based patents, and to Ministries and Industry for non-science-based patents (for search terms see the legend at the end of Table 4). General conclusion can be that the number of technological (non-science) based patents is higher than that of academic (science-based) patents, with some specific field of applications, where the situation is the opposite (e.g. "Debris flow(s)", "Landslide displacement", "Landslide monitoring").

3.3 Patent Documents and Technical Field

We have classified the landslide-related patent documents from two databases: (i) the Espacenet using 4 search terms (Debris flow(s), Falling rock(s), Landslide(s), Mud flow(s)) in Title, and (ii) Derwent innovation Index using the same 4 search terms in Topic. We applied the International Patent Classification (IPC 2022), and the results are given in Tables 5 and 6. The total number of patent documents in Tables 5 and 6 can vary as patents documents can be attributed to more than just one category. The Derwent Innovation Index database yields more landslide-related patent documents than the Espacenet database.

In both databases, the prevailing patent documents are found by searching the term "Landslide(s)", followed by the term "Debris flow(s)", "Falling rock(s)" and "Mud flow(s)". With regard to the different areas of technology to which landslide-related patent documents pertain, the categories

Table 1 Results of landslide-related patent documents found in the Espacenet database (EPO 2022b)

Search term	Part of the patent document					
	Title	Abstract	Claims	Title, abstract or claims	Description	All text fields
Earth flow(s) = Earth-flow(s)	14	68	93	162	580	691
Earth slide(s) = Earth-slide(s)	10	39	17	60	135	188
Debris flow(s)	1141	1742	2170	2787	11,315	11,754
Debris flow early warning	33	47	58	79	124	140
Debris flow monitoring	56	84	113	141	273	286
Deep seated landslide(s) = Deep-seated landslide(s)	1	4	2	6	8	12
Earthquake landslide(s)	10	39	25	48	276	291
Earthquake induced landslide(s) = Earthquake-induced landslide(s)	3	4	2	4	45	47
Falling rock(s) = Falling-rock(s)	385	976	1166	2008	9765	10,111
Falling stone(s)	212	635	430	1090	3195	3718
Landslide(s)	3383	7028	8520	11,985	50,733	52,423
Landslide activity	2	3	5	6	88	88
Landslide dam break	1	3	3	5	7	9
Landslide deformation	36	94	108	154	490	503
Landslide depth	4	8	9	15	46	52
Landslide detection	48	68	117	144	373	390
Landslide disaster(s)	110	309	301	472	2446	2484
Landslide displacement	79	131	172	205	466	478
Landslide drainage	5	10	12	16	39	42
Landslide early warning	83	155	72	173	208	281
Landslide early warning method	27	29	21	36	24	40
Landslide early warning system	20	24	22	35	38	48
Landslide emergency	13	27	18	34	93	101
Landslide hazard	42	63	163	191	621	651
Landslide mitigation	0	0	1	1	11	12
Landslide monitoring	285	448	439	579	1442	1504
Landslide observation	2	4	10	11	58	58
Landslide reinforcement	8	11	21	28	103	106
Landslide retaining	13	13	19	32	52	63
Landslide risk	39	121	116	182	408	454
Landslide safety	12	29	32	48	87	96
Landslide stability	18	64	61	96	274	288
Landslide susceptibility	20	22	36	41	91	94
Landslide velocity	0	1	8	8	16	16
Landslide vulnerability	0	2	4	4	20	20
Mudflow(s)	82	130	234	382	1309	1542
Mud flow(s) = Mud-flow(s)	103	700	2162	2661	12,615	13,213
Preventing landslide(s)	73	108	143	238	888	988
Rainfall-induced landslide(s)	12	18	18	27	104	109
Rock avalanche(s)	1	5	13	18	97	103
Rock fall(s) = Rock-fall(s)	171	380	722	1026	4855	5235
Shallow landslide(s)	15	30	30	44	286	293
Submarine landslide(s)	43	52	62	68	359	398

Table 2 Results of landslide-related patent documents found in the Google Patents database (Google 2022)

Search term	Part of the patent document			
	Title	Abstract	Claims	Title, abstract and claims
Earth flow(s)	518	38,674	135,828	254
Earth slide(s)	279	56,539	135,828	87
Debris flow(s)	6781	135,828	135,828	3845
Debris flow early warning	123	604	6064	108
Debris flow monitoring	215	8914	46,251	158
Deep seated landslide(s)	0	19	42	0
Earthquake landslide(s)	65	409	453	54
Earthquake induced landslide(s)	14	82	103	10
Falling rock(s)	1075	9431	12,913	490
Falling stone(s)	470	9015	17,808	129
Landslide(s)	4694	10,354	10,813	3872
Landslide activity	3	109	304	3
Landslide dam break	12	72	113	10
Landslide deformation	121	1152	1338	105
Landslide depth	106	728	1535	98
Landslide detection	252	1304	2192	204
Landslide disaster(s)	262	1672	1316	224
Landslide displacement	201	1155	1664	197
Landslide drainage	67	785	950	46
Landslide early warning	322	863	1183	299
Landslide early warning method	134	418	610	119
Landslide early warning system	147	491	862	134
Landslide emergency	44	261	297	39
Landslide hazard	147	1163	1065	121
Landslide mitigation	243	817	999	133
Landslide monitoring	845	2304	2534	788
Landslide observation	825	2390	2719	759
Landslide reinforcement	116	1178	1243	99
Landslide retaining	62	629	756	48
Landslide risk	118	659	727	98
Landslide safety	37	1507	912	34
Landslide stability	67	1650	1170	49
Landslide susceptibility	24	43	71	21
Landslide velocity	33	529	1,313	32
Landslide vulnerability	69	450	535	60
Mudflow(s)	4614	10,961	13,784	3756
Mud flow(s)	2211	52,130	124,229	1334
Preventing landslide(s)	477	3109	2450	304
Rainfall-induced landslide(s)	35	153	199	29
Rock avalanche(s)	164	13,586	15,558	66
Rock fall(s)	2288	29,891	37,681	1455
Shallow landslide(s)	32	128	148	26
Submarine landslide(s)	57	154	413	50

Table 3 Results of landslide-related patent documents found in the Derwent Innovation Index database (Clarivate 2022a)

Search term	Part of the patent document	
	Title	Topic
Earth flow(s) = Earth-flow(s)	5	22
Earth slide(s) = Earth-slide(s)	2	13
Debris flow(s)	1082	1854
Debris flow early warning	35	67
Debris flow monitoring	49	73
Deep seated landslide(s) = Deep-seated landslide(s)	1	1
Earthquake landslide(s)	23	95
Earthquake induced landslide(s) = Earthquake-induced landslide(s)	1	1
Falling rock(s) = Falling-rock(s)	140	496
Falling stone(s)	342	1011
Landslide(s)	3273	6553
Landslide activity	0	2
Landslide dam break	0	1
Landslide deformation	63	127
Landslide depth	4	12
Landslide detection	39	62
Landslide disaster(s)	211	444
Landslide displacement	101	159
Landslide drainage	4	5
Landslide early warning	81	136
Landslide early warning method	21	25
Landslide early warning system	24	33
Landslide emergency	13	20
Landslide hazard	24	61
Landslide mitigation	0	1
Landslide monitoring	316	454
Landslide observation	1	6
Landslide reinforcement	3	8
Landslide retaining	4	6
Landslide risk	43	118
Landslide safety	12	26
Landslide stability	23	46
Landslide susceptibility	9	12
Landslide velocity	0	0
Landslide vulnerability	3	4
Mudflow(s)	48	146
Mud flow(s) = Mud-flow(s)	112	497
Preventing landslide(s)	58	225
Rainfall-induced landslide(s)	11	15
Rock avalanche(s)	7	11
Rock fall(s) = Rock-fall(s)	210	662
Shallow landslide(s)	14	24
Submarine landslide(s)	34	49

Legend Topic = Title and Abstract

Table 4 Landslide-related patent documents with at least 100 claims found in the Espacenet database (EPO 2022b), with respect to inventors and applicants' category

Landslide-related patent documents		Inventors and applicants from			
Search term	No. of Claims	Academic institutions	Research institutions	Ministries	Industry
Debris flow(s)	2170	605	480	48	705
Debris flow monitoring	113	30	21	5	51
Falling rock(s) = Falling-rock(s)	1166	183	105	14	525
Falling stone(s) = Falling-stone(s)	430	76	64	3	190
Landslide(s)	8520	1988	935	110	3659
Landslide deformation	108	56	19	2	28
Landslide detection	117	25	17	2	47
Landslide disaster(s)	301	106	55	8	91
Landslide displacement	172	91	15	2	49
Landslide hazard	163	83	28	11	44
Landslide monitoring	439	173	51	3	170
Landslide risk	116	46	32	3	28
Mudflow(s)	234	24	39	3	31
Mud flow(s) = Mud-flow(s)	2162	176	170	13	773
Preventing landslide(s)	143	13	13	1	50
Rock fall(s) = Rock-fall(s)	722	55	45	6	264

Legend abbreviations used for Academic institutions (College, University, Univ), Research Institutions (Institute, Research, Res, Inst), Ministries (Ministry, Min), Industry (Co, Comp, Eng, Ltd, Plc)

Table 5 International Patent Classification (IPC 2022) used for classification of patents and utility models according to the different areas of technology to which they pertain. Selected landslide-related patent documents from the Espacenet database (EPO 2022b), with respect to the field of IPC

		Search term in title			
	Category of IPC	Debris flow(s)	Falling rock(s)	Land-slide(s)	Mud flow(s)
A	Human necessities	14	5	70	2
A01	*Agriculture; Forestry; Animal husbandry; Hunting; Trapping; Fishing*	*11*	*2*	*58*	*2*
B	Performing operations; Transporting	25	14	84	3
C	Chemistry; Metallurgy	9	2	22	1
D	Textiles; Paper	0	4	1	0
E	Fixed constructions	512	309	1276	75
E01	*Constructions of roads, railways, or bridges*	*115*	*283*	*126*	*3*
E02	*Hydraulic engineering; Foundations; Soil-shifting*	*419*	*55*	*1115*	*21*
E03	*Water supply; Sewerage*	*22*	*0*	*68*	*0*
E21	*Earth or rock drilling; Mining*	*22*	*18*	*107*	*53*
F	Mechanical engineering; Lightning; Heating; Weapons; Blasting	21	24	67	6
G	Physics	660	52	2125	42
G01	*Measuring; Testing*	*295*	*35*	*1235*	*30*
G06	*Computing; Calculating or counting*	*210*	*15*	*512*	*5*
G08	*Signalling*	*233*	*20*	*700*	*12*
G09	Educating; Cryptography; Display; Advertising; Seals	*34*	*2*	*112*	*0*
H	Electricity	33	8	158	1
H02	*Generation, conversion, or distribution of electric power*	*9*	*3*	*56*	*0*
H04	*Electric communication technique*	*21*	*2*	*94*	*1*
A-H	Total patent documents	1141	385	3383	103

Legend Categories A to H are taken from the IPC

Table 6 International Patent Classification (IPC 2022) used for classification of patents and utility models according to the different areas of technology to which they pertain. Selected landslide-related patent documents from the Derwent Innovation Index database (Clarivate 2022a), with respect to the field of IPC

		Search term in topic			
	Category of IPC	Debris flow(s)	Falling rock(s)	Land-slide(s)	Mud flow(s)
A	Human necessities	89	22	566	32
A01	*Agriculture; Forestry; Animal husbandry; Hunting; Trapping; Fishing*	*47*	*7*	*419*	*25*
B	Performing operations; Transporting	224	90	683	102
B65	*Conveying; Packing; Storing; Handling thin or filamentary material*	8	8	*123*	5
C	Chemistry; Metallurgy	40	11	163	88
D	Textiles; Paper	3	5	17	1
E	Fixed constructions	734	336	2525	268
E01	*Constructions of roads, railways, or bridges*	*142*	*178*	*276*	*15*
E02	*Hydraulic engineering; Foundations; Soil-shifting*	*530*	*89*	*2059*	*51*
E03	*Water supply; Sewerage*	*58*	*0*	*219*	*4*
E21	*Earth or rock drilling; Mining*	*68*	*105*	*249*	*199*
F	Mechanical engineering; Lightning; Heating; Weapons; Blasting	83	45	214	49
G	Physics	872	78	3186	80
G01	*Measuring; Testing*	*375*	*43*	*1791*	*48*
G06	*Computing; Calculating or counting*	*256*	*22*	*856*	*16*
G08	*Signalling*	*326*	*26*	*1029*	*15*
G09	Educating; Cryptography; Display; Advertising; Seals	*34*	*7*	*130*	*2*
H	Electricity	78	20	420	14
H02	*Generation, conversion, or distribution of electric power*	*23*	*4*	*129*	*6*
H04	*Electric communication technique*	*47*	*10*	*249*	*8*
A-H	Total patent documents	1854	496	6553	497

Legend Categories A to H are taken from the IPC

"G-Physics" and "E-Fixed constructions" are clearly prevailing: "G" for debris flows and landslides, and "E" for fallings rocks and mudflows. Other IPC categories are much less present—in the order of a few percentages.

Within the category "E-Fixed constructions", the most abundant is category "E02-Hydraulic engineering; Foundations; Soil-shifting" (roughly one third of all landslide-related patent documents). Within the category "G-Physics", the most abundant is category "G1- Measuring; Testing" followed by "G08-Signalling".

3.4 Patent Families, Country of Publication

For the analysis of landslide-related patent documents with regard to the country of publication we used patent family distribution in the Espacenet, the Google Patents, and the Derwent Innovation Index databases for 4 search terms in titles of patent documents ("Debris flow(s)", "Falling rock (s)", "Landslide(s)", "Mud flow(s)"). In all three databases, the most abundant category of patents was related to "Landslide(s)", followed by "Debris flow(s)". For country codes we used the two-letter abbreviations from the Espacenet. The search string for the Espacenet database was limited to the Title. The search string for the Google Patents database was limited to Title, Abstract, and Claim: e.g. (TI = (debris flow)) (AB = (debris flow)) (CL = (debris flow)) country:EP. The search in the Derwent Innovation Index was performed for Topics, covering patent titles and abstracts, and country of publication was searched in the Patent Number. The results are given in Tables 7, 8 and 9.

The majority of all landslide-related patents are filled and/or granted in China (abbr. CN). This is a bit less so pronounced for patents related for falling rock(s) and mud flow(s). Due to China contribution, the five major emerging economies: Brazil, Russia, India, China, and South Africa, are outperforming the rest of the world, also major developed countries: USA, European Union, Japan and Republic of Korea. The majority of landslide-related patents are issued by national patent offices in single countries, and thus the contribution of the World Intellectual Property Organization (WIPO) and the European Patent Office (EPO) jointly is only

Table 7 The number of patent families of landslide-related patent documents from the Espacenet database (EPO 2022b), with respect to the country of patent publications

		Search term in title			
Code	Country of patent publication	Debris flow(s)	Falling rock(s)	Landslide(s)	Mud flow(s)
AT	Austria	1	9	5	1
AU	Australia	3	4	10	7
BR	Brazil	1	4	2	4
CA	Canada	2	3	6	10
CH	Switzerland	3	11	6	1
CN	China	1052	128	2802	38
DE	Germany	0	8	11	6
EP	European Patent Office (EPO)	3	16	14	6
FR	France	0	3	6	5
GB	United Kingdom	2	0	3	7
IN	India	0	0	0	0
IT	Italy	1	4	7	0
JP	Japan	32	67	311	6
KR	Republic of Korea	58	181	112	0
RU (SU)	Russian Federation (Soviet Union)	0 (0)	2 (2)	81 (48)	9 (11)
TW	China Taipei	8	5	21	5
US	United States of America	17	11	27	30
WO	World Intellectual Property Organization (WIPO)	20	8	36	10
ZA	South Africa	4	2	3	3
	Total patent documents	1157	386	3460	104

Legend Country codes are taken from the Espacenet

a few percentages, in all three databases. This is in line with the general picture of the world patent applications.

Cheng and Drahos (2018) studied China Patent Office and concluded that in 2011 the Chinese patent office overtake U.S. in terms of patent applications and became the biggest patent office in the world. From 2010 to 2020, the proportion of international patents granted to inventors from high-income countries fell from 78 to 48% (NSB & NSF 2022). The U.S. share of international patents declined from 15 to 10%. The same share declined from 35 to 15% for Japan and 12% to 8% for the EU-27. In contrast, China's share of international patents increased from 16% in 2010 to 49% in 2020.

WIPO (2021) reports that in 2020 in total 45.7% of all patent applications worldwide was filled in China (1,497,159 out of 3,276,700 applications). With regards to patent applications, China was followed by USA, Japan, Republic of Korea, Germany, France, UK, Switzerland, India, and the Netherlands—considering resident and non-resident patent applicants. In the field of landslide-related patents, India and the Netherlands are much less active, and also USA are behind Japan and Republic of Korea, but in front of EU member countries.

Following the undisputed China as number one, the next strongest countries in patent applications are: USA and Republic of Korea for debris flow(s), Republic of Korea and Japan for falling rock(s) and for landslide(s), and USA for mud flow(s).

3.5 Patent Documents Citations

The annual number of patent applications in the world can be taken from the World Bank data (World Bank 2022a, b), the data for 1990, 2000, 2019 and 2020 are presented in Table 10. Worldwide, there is a steady growth of patent applications, from less than 1 million in 1990 to over 3 million in 2020. Residents of countries where patent applications were filled, are generally outnumbering non-residents for many countries, but not in Australia, Brazil, Canada, India, South Africa, and USA.

Looking at the World Bank data (data.worldbank.org), since 2000 the ratio between the number of scientific and technical journal articles published in the World to the number of patent applications in the World is roughly 1:1, in favor of the patent applications for a few 10%—in 2000:

Table 8 Selected landslide-related patent documents from the Google Patent database (Google 2022), with respect to the country of patent publication

		Search term in title, abstract, and claim			
Code	Country of patent publication	Debris flow(s)	Falling rock(s)	Landslide(s)	Mud flow(s)
AT	Austria	2	0	0	0
AU	Australia	9	3	3	3
BR	Brazil	10	1	1	1
CA	Canada	22	1	2	14
CH	Switzerland	5	0	1	0
CN	China	3142	284	3508	1059
DE	Germany	120	1	5	27
EP	European Patent Office (EPO)	37	5	6	18
FR	France	17	0	0	0
GB	United Kingdom	9	0	0	5
IN	India	0	0	0	0
IT	Italy	0	0	0	0
JP	Japan	78	143	145	11
KR	Republic of Korea	90	54	66	9
RU (SU)	Russian Federation (Soviet Union)	14 (0)	0 (0)	82 (20)	22 (22)
TW	China Taipei	14	2	3	2
US	United States of America	114	4	19	52
WO	World Intellectual Property Organization (WIPO)	75	6	23	30
ZA	South Africa	0	0	0	0
	Total patent documents	3880	494	3937	1341

Legend Country codes are taken from the Espacenet

1,377,500 patent applications to 1,066,335 articles; in 2018: 3,325,500 patent applications to 2,554,319 articles. Both categories are growing, but the ratio remains approximately stable. The annual productivity of scientific articles can also be estimated using Scimago data (SJR 2022) that gives the productivity in 2021 in the world close to 5 million citable documents (articles, reviews, and conference papers). This estimate is higher than the of the World Bank, since also conference papers are taken into account.

For the analysis on patent document citations in scientific articles, we have selected two databases, SpringerLink and SCOPUS. The search string for SpringerLink was done within Articles "patent AND (landslides OR "debris flow" OR "falling rock" OR mudflow)", and the search string for SCOPUS database was: ALL ("debris flow" OR "falling rock" OR landslide OR "mud flow") AND patent AND (LIMIT-TO (DOCTYPE, "AR")) AND (LIMIT-TO (SUBJAREA, "EQART") OR LIMIT-TO (SUBJAREA, "ENGI")) AND (LIMIT-TO (SRCTYPE, "j"))—the search was for landslide-related and patent-related articles published in journals limited to two subject areas of "Earth and Planetary Science" and "Engineering", respectively, for the period between 2012 and 2021. The results of this search are given in Table 11. Even though SCOPUS was limited to only two subject areas, the number of citing landslide-related patent documents was comparable to SpringerLink. The absolute number of citations is extremely low (a few tens of citations per year only), having in mind the total number of landslide-related patent documents (Tables 7, 8 and 9). Only a fraction of the order of a few one-in-thousands of landslide-related patents documents are cited annually in journal review and research articles. This situation does not change, if we add mentions of patent documents to their citations.

Finally, we have selected 10 landslide-related journals from the Web of Science database that regularly publish scientific articles and technical papers on landslide science and technology. Half of them were as such already recognized by Mikoš (2017), who studied top publications in geological engineering and engineering geology. We searched for those published articles in these ten journals that are citing patent documents and are to some extent related to landslide risk reduction. Table 12 shows all those 45 landslide-related articles that cite a patent document as a reference (14 articles) or at least mention patents in the text (31 articles). This analysis is another proof that landslide-related patent documents are extremely rarely cited in scientific literature if measured by journal articles.

Table 9 Selected landslide-related patent documents from the Derwent Innovation Index database (Clarivate 2022a), with respect to the country of patent publications searched in the Patent Number

		Search term in topic			
Code	Country of patent publication	Debris flow(s)	Falling rock(s)	Landslide(s)	Mud flow(s)
AT	Austria	1	2	0	0
AU	Australia	12	5	21	11
BR	Brazil	2	3	20	10
CA	Canada	9	7	17	34
CH	Switzerland	2	4	7	1
CN	China	1739	232	5659	337
DE	Germany	4	52	15	1
EP	European Patent Office (EPO)	21	22	49	36
FR	France	1	10	13	0
GB	United Kingdom	2	4	4	14
IN	India	5	6	46	4
IT	Italy	0	4	16	2
JP	Japan	25	16	400	24
KR	Republic of Korea	39	162	235	9
RU (SU)	Russian Federation (Soviet Union)	3 (0)	7 (0)	77 (0)	18 (0)
TW	China Taipei	5	1	32	6
US	United States of America	71	26	140	118
WO	World Intellectual Property Organization (WIPO)	48	28	141	66
ZA	South Africa	1	2	3	1
	Total patent documents	1887	484	6553	514

Legend Country codes are taken from the Espacenet

Table 10 Patent applications in the World Bank database (i.e. World Development Indicators), given for selected countries where patents were filled, and separately for residents and non-residents (World Bank 2022a, b)

		Residents				Non-residents		
Country	1990	2000	2019	2020	1990	2000	2019	2020
Australia	–	1928	2637	2368	–	20,073	27,121	26,926
Austria	2025	1961	2066	2124	670	340	208	173
Brazil	2389	3179	5464	5280	5148	14,104	19,932	19,058
Canada	2549	4187	4238	4452	24,375	35,435	32,250	30,113
China	5853	25,397	1,243,914	1,345,243	5,365	34,804	173,317	173,538
France	12,378	13,870	14,103	12,771	4260	3483	1766	1542
Germany	30,724	51,736	46,632	41,260	8605	10,406	20,802	19,845
India	1147	2206	19,454	23,141	2673	6332	34,173	33,630
Italy	–	7877	9229	10,061	–	1396	898	947
Japan	333,230	387,364	245,372	227,348	34,360	49,501	62,597	61,124
Korea, Republic of	9082	72,831	171,603	180,477	16,738	29,179	47,372	46,282
Russian Federation	–	23,377	23,337	23,759	–	8960	12,174	11,225
South Africa	1093	895	567	542	4943	2400	6347	6146
Switzerland	2987	2083	1369	1384	1081	468	348	301
United Kingdom	19,310	22,050	12,061	11,990	8928	10,697	7189	8659
United States of America	90,643	164,795	285,113	269,586	80,520	131,100	336,340	327,586
World	687,700	874,800	2,231,800	2,304,400	309,800	502,700	994,300	972,300

Table 11 Number of journal review and research articles in SpringerLink and SCOPUS citing landslide-related patent documents (Elsevier 2022; Springer Nature 2022a)

	SpringerLink			SCOPUS		
Year	Patent-related articles	Citing patent documents	Mentioning patents	Patent-related articles	Citing patent documents	Mentioning patents
2021	27	3	2	37	1	–
2020	19	4	–	22	–	2
2019	11	2	–	10	–	-
2018	13	–	–	16	–	2
2017	18	4	5	20	1	-
2016	10	1	–	13	2	2
2015	23	1	2	21	–	2
2014	11	1	2	6	–	–
2013	6	1	1	11	–	1
2012	7	1	–	4	–	–
In total						

Table 12 Cited landslide-related patent documents in the ten selected landslide-related journals from the Web of Science database (Clarivate 2022b)

Journal (period under study)	Articles citing a patent (WoS citations)	Citation from the text	As a references
Acta Geotechnica (2006–2022)	Wu et al. (2021) (1 citation)	A patented additive was developed to be added to the air injection to accelerate consolidation of soft ground so that the fractures remain stable for longer time	Wu (2015)
	Di Prisco and Pisanò (2014) (5 citations)	A recently patented device (tensioned elements TFEG®—Guided Extrusion Force Transfer) has been taken as a reference for numerical analyses, trying to keep the geometrical configuration as simple as possible, but sufficiently accurate to reproduce the most relevant structural details	No
Bulletin of Engineering Geology and the Environment (2015–2022)	Kahraman et al. (2022) (no citations)	Patented hard rock Tunnel Boring Machine (TBM) cutterhead equipped with microwave generating mechanism Patented microwave assisted rock cutting method	Feng et al. (2019) Lindroth et al. (1991)
	Ying et al. (2021) (1 citation)	A casing and grouting method for micropiles, small-diameter drilled piles	Groneck and Amour (2000)
	Wang et al. (2021b) (no citations)	The research team of the author developed patented triaxial apparatus for unsaturated soil that can control the suction in soil	No
	Xue et al. (2021) (no citations)	A patented soil matric potential sensor was used in the study (Patent No.: DE10164018B4)	No
	Wang et al. (2021a) (7 citations)	Patented rock straight shear rheometer	No
	Zhou et al. (2021) (1 citation)	A patented electrically conductive wick drain and a specially designed automated power supply to carry out field electroosmosis tests on a sludge landfill site	No
	Wei et al. (2020) (4 citations)	Patented SH agent made of modified PVA and water is a nontoxic liquid and a soluble polymer, has 6% solid matter and generates a film and a silk-like web in soil after drying, and the film is insoluble in water	No

(continued)

Table 12 (continued)

Journal (period under study)	Articles citing a patent (WoS citations)	Citation from the text	As a references
	Jiang et al. (2020) (no citations)	Patent pending floating ball method (FBM) is a groundwater level monitoring technique for vacuum preloading	No
	Cui et al. (2019) (13 citations)	A patented non-disturbance sampling technique for rock cores under high in situ stress relaxation during the coring procedure	No
	Mastrorocco et al. (2018) (12 citations)	Patent pending Leica™ TruView is a plug-in that allows visualization of 3D Virtual Reality (VR)	No
	Li et al. (2017) (6 citations)	A patented device for estimating joint roughness coefficient (JRC) and peak shear strength of rock joints by the National Patent Office of China	No
	Fan et al. (2017) (6 citations)	Deep dislocation displacement monitoring of the slip surface is typically obtained from the advised method in the patented "device about measuring the depth of slip surface and deep dislocation displacement"	Meng et al. (2007)
	Ghobadi et al. (2015) (7 citations)	Patented method Hydroxylating Conversion Treatment (HCT)] has been used to protect carbonate stones such as marble, limestone and travertine	US (2001)
Computers and Geotechnics (1985–2022)	Li et al. (2020) (2 citations)	A new design with non-uniform thickness geotextile mats, where the height of geotextile mats varies, i.e. shorter mats were used close to the bottom while relatively higher mats were used for the top layers, was proposed and patented to enhance the stability of dike	No
	Cai et al. (2019) (26 citations)	The artificial ground freezing technique was patented by German mining engineer F. H. Poetsch in 1883	No
	Vitel et al. (2015) (74 citations)	Patented by Poetsch in Germany in 1883, the artificial ground freezing technique (AGF) appeared 150 years ago in coal mines in South Wales	No
	Park et al. (2011) (5 citations)	The electric discharge occurs through the Electro-power impact cell (Korea patent 10–2009-0,113,602)	No
	Fan and Hsieh (2011) (13 citations)	A series of connecting elements are used to incorporate reinforced earth embankments with soil nails. The connecting element, improved from a patented connecting method (Chou and Fan 2004), consists of a series of stainless steel wire ropes and stainless steel pipes	Chou and Fan (2004)
	Cividini et al. (2011) (1 citation)	A key point of the technology used in this study is represented by a valve, internationally patented by Visconti Fondazioni (Milan, Italy), that seals the bottom section of the casing	No
	Chupin et al. (2009) (18 citations)	A sleeved grout pipe and a double packer are used to inject grout into sand. A patented cement-based grout, similar to those manufactured for fieldworks, is utilized	No
Engineering Geology (1965–2022)	Comina et al. (2021) (no citations)	In this study, the application an innovative (patent pending) soil improving system by injections of a sand/gravel mixture was evaluated	No
	Li et al. (2021) (2 citations)	The B–P shear test system consists of a YSD-200 two-dimensional fracture tester for rock and soil with a special fixture, which was developed and patented	No

(continued)

Table 12 (continued)

Journal (period under study)	Articles citing a patent (WoS citations)	Citation from the text	As a references
	Tan et al. (2020) (2 citations)	A patented door-opening system is utilised to assist the door opening process for initiating debris flows uniformly and quickly	No
	Massimi et al. (2016) (2 citations)	Twisting Theory (TWT) and Twisting Algorithm (TWA) were developed by M. Buscema in 2010 at Semeion Research Center of Sciences of Communication in Rome and are protected (Buscema 2014)	Buscema (2014)
Geomorphology (1987–2022)	Vayssière et al. (2019) (5 citations)	The automatic resistivity profiling (ARP) uses a patented multi-electrode device that is connected to wheel-based electrodes that roll over the ground surface	No
	Chambers et al. (2011) (109 citations)	Mobile resistivity mapping was undertaken using the automated resistivity profiling (ARP) technique, which uses a patented multi-electrode device (Geocarta SA, France) in order to make direct current (DC) measurements of subsurface electrical resistivity along profiles with the aim of producing horizontal property maps	No
	Prior and Hooper (1999) (30 citations)	The Enhanced Surface Rendering (ESR) is a patented method used for high-quality data acquired in water depths greater than 250 m, to display data as an artificially illuminated surface depicting bottom morphology and/or acoustic amplitude	No
	Florinsky (1996) (26 citations)	Digital elevation models (DEMs) and DEM analysis methods are used for fault recognition as about 90% of fault geomorphic indices can be defined quantitatively—also the patented technique of thalweg revealing	Eliason and Eliason (1987)
Geotextiles and Geomembranes (1984–2022)	Koerner and Koerner (2018) (36 citations)	In 1966, H. Vidal of France wrote the first of several papers on “reinforced earth”, a technique he initiated, developed, patented and promoted (Vidal 1969)	Vidal (1969)
	Hou et al. (2017) (25 citations)	Zhang (2005) proposed a patented horizontal-vertical (H-V) reinforcement that attached several small inclusions vertically to the horizontal reinforcement	Zhang (2005)
	Koerner and Koerner (2013) (85 citations)	In 1966, H. Vidal of France wrote the first paper on reinforced earth, a technique he initiated, developed, patented and promoted (Vidal 1969)	Vidal (1969)
	Liu et al. (2009) (8 citations)	The second method is to embed two shielded thin copper wires in the Prefabricated vertical drain (PVD),—this method has been patented (Ren 2004)	(Ren, 2004)
	Koerner and Koerner (2006) (86 citations)	Flexible sand-filled tubes were made as early as 1957, but they were not very successful. Eventually in 1967, a patent was granted to a Danish firm	No
	Hazarika (2006) (68 citations)	Geofoam usage dates as far back as the 1960s, when a patent for using geofoam as pavement insulation was granted in the USA	No
	Koerner and Koerner (1996) (6 citations)	Efforts to form flexible sand-filled tubes were made as early as 1957, but were not very successful. Eventually, in 1967, a patent was granted The process of joining two sheets of geotextiles to form erosion control mattresses was developed in 1965, and numerous patented systems are available	No

(continued)

Table 12 (continued)

Journal (period under study)	Articles citing a patent (WoS citations)	Citation from the text	As a references
Journal of Geotechnical and Geoenvironmental Engineering (2000–2022)	Holtz (2017)	Some years ago, French architect Henri Vidal invented a system he called Terre Armée (Reinforced Earth) for construction of retaining walls. Reinforced Earth has three primary components: select granular backfill, galvanized steel strips for reinforcement, and precast concrete facing panel elements. Worldwide patents were granted in 1966, and by the early 1970s the technology was well established in France and several other countries	No
Landslides (2004–2022)	Rossi et al. (2018) (96 citations)	Innovative circular-shaped airframe fully supporting flight dynamics of a multicopter drone, patented in Italy and patent pending in EU and USA	No
	Xiao et al. (2017) (17 citations)	Soil mixture to promote vegetation for slope protection and landslide prevention (patented in 1980's)	No
	Lu et al. (2014) (77 citations)	Patented PSInSAR™ technique	No
Natural Hazards (1989–2022)	Du et al. (2020) (no citations)	A transparent experimental device to study the migration mechanism of fine particles in aquifers during water injection was patented	No
	Kazeev and Postoev (2017) (4 citations)	Institute of Environmental Geosciences of Russian Academy of Sciences (IEG RAS) has developed the criteria for limit state of the soil mass, and the methodology of the limit-state calculations, and these numerical simulations received three patents. Based on the patented methodology for limit-state analysis, a new practical method to increase slope resistance has been developed and patented. It involves construction of artificial cuts similar to erosional downcuts of natural gully or ravine	No
Rock Mechanics and Rock Engineering (2000–2022)	Castanon-Jano et al. (2017) (27 citations)	Since 1975, numerous devices have been invented to improve the dynamic behavior of falling rock protection barriers. In total, 174 patent families (inventions) have been found describing a new energy dissipating device or a new barrier in which these devices play an important role. The 174 patent families represent 120 different assignees, Fatzer (a company of the Brugg group) and Pfeifer Isofer being the most significant in both numbers of applications and granted IPR (intellectual property rights)	Thomel (1998) Von Allmen (2004) Moreillon (2006)
	Ishida et al. (2017) (66 citations)	Acoustic emission (AE) monitoring due to the stress memory effect has been applied to stress measurement in rocks, the application was patented by Kanagawa and Nakasa (1978)	Kanagawa and Nakasa (1978)

4 Conclusions and Further Work

The analysis of landslide-related patent documents, using three patent databases (Escapenet, Google Patents, Derwent Innovation Index) was performed to assess to which extent landslide science and technology is mirrored in patent applications, and what is the share of academic versus non-academic institutions. In the second part of the analysis, technical fields of patent applications were studied and countries that are the most productive ones with regard to landslide-related patent applications were searched for. The study finished by patent citation analysis in published scientific literature. The results of this study can be summarized as follow:

(i) In the Google Patents database there is 15,000 + landslide-related patent documents, and in the Espacenet and the Derwent Innovation Index database 5000+, respectively. In the patents' titles, abstracts and claims, processes are more often used to describe the patent than the technology.

(ii) The number of technological (non-science) based patents is higher than that of academic (science-based) patents, with some specific field of applications, where the situation is the opposite.

(iii) With regard to the different areas of technology to which landslide-related patent documents pertain, the categories "G-Physics" and "E-Fixed constructions" are clearly prevailing: "G" for debris flows and landslides, and "E" for fallings rocks and mudflows.

(iv) The majority of landslide-related patents are filled and/or granted in China, followed by Japan and South Korea, USA and EU member countries—five major emerging economies (called BRICS) are outperforming developed countries, with a very prevailing Chinese contribution.

(v) Only a fraction of the order of a few one-in-thousands of landslide-related patents documents are cited in journal review and research articles.

Further analyses of landslide-related patent documents may be done with regard to other scientific information sources such as conference proceedings, or also to social media such as Twitter or Researchgate. Nevertheless, it is quite obvious that landslide-related patent documents are not studied by landslide scientists and researchers, hopefully this important category of intellectual property finds much more application in real word solutions when planning and executing landslide disaster risk reduction.

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