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SAND REMOVAL FROM SANDSTONE CLIFFS AS THE MAIN FACTOR INFLUENCING PROPERTIES OF ORGANIC SOILS – A CASE STUDY OF TRANSITIONAL BOG IN THE STOŁOWE MOUNTAINS

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Abstract. With this paper we investigate the effect of sand contribution to organic soils and direct influence of this process on the physical and physicochemical properties on the example of transitional bog in the Stołowe Mountains (the Central Sudetes), which was periodically covered by sand material from sandstone cliffs weathering. Field survey and soil sampling were conducted in August 2015 in the area of Białe Skały. Soil material for laboratory analysis was collected from three peat cores, while soil samples were collected from each soil horizon distinguished in each core. Obtained results indicate the great impact of mineral material admixture on soil properties, both physicochemical and chemical. Recorded values of each soil parameter in the organic horizons adjacent to the mineral interlayers differ considerably from those obtained in the soil profile free of sand admixtures. Preliminary study of soil cover of transitional bog will allow correct planning of palaeoecological research about genesis and evolution of this peatland.

Keywords: peatlands, mineral interlayers, sandstones, soil properties, the Sudetes

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INTRODUCTION

Peat, thus organic soils, is sedentarily accumulated material consisting of at least 20% of organic material, which accumulated as a result of limited decay of peat-forming plants in the area periodically inundated or saturated by water (Joosten and Clarke 2002). During the peat accumulation, many abiotic (hydrology, climate, geomorphology) and biotic factors (fauna, flora, human activity) affect this process, thereby organic soil properties (Wüst-Galley *et al*. 2016). Decomposition stage of fiber is the fundamental feature, that determines various physical soil properties, e.g. bulk density, water retention and saturated hydraulic conductivity (Nichols and Boelter 1984). Whereas the most important factors determining the chemical and geobotanical composition of the organic material is peat-forming plants structure (Laine *et al*. 2011, Glina *et al*. 2017) and type of water supply (Glina *et al*. 2016a). However, in some cases the trophy status changes might be an effect of mineral strata contribution to organic soils (Bogacz 2005). The same author, based on the Sudetes peatland study, reported that mineral admixtures or interlayers might cause the periodical inhibition of peat accumulation process. The phenomenon of mineral materials admixtures to organic soil is wider and more complex in mountain peatlands, in particular (Glina and Bogacz 2016). In general, admixed material is usually of fluvial origin (Bogacz and Rutkowska 2010, Bogacz and Roszkowicz 2010, Glina *et al*. 2013, Glina *et al*. 2016a, 2016b). Nonetheless, mineral layers in organic soils, might be also a result of slope processes, e.g. in the areas of sloping peatlands in the Central Sudetes (Glina *et al*. 2013) or landslide peat bogs in the Carpathians (Margielewski 2006, 2014; Margielewski *et al*. 2011). Mineral layers may have different thickness and origin, sometimes occur as a thin peat-mineral lamellae or thick mineral cover on peat, which indicates the dynamics of sedimentary environment (Margielewski 2014). The aim of this study was to analyze the effect of mineral admixtures (sand) from sandstone escarpments on the physical and physicochemical properties of organic soils from transitional bog in the Stołowe Mountains (the Central Sudetes). Preliminary soil study will allow correct planning of palaeoecological research on genesis and evolution of this peatland.

MATERIALS AND METHODS

Study area

The Stołowe Mountains are situated in the south-western part of Poland (central Sudetes), at the border with Czechia (Fig. 1a). The Stołowe Mountains are underlain by ca. 400m thick succession of sandstones and fine-grained rocks: marls, mudstones and calcareous sandstones (Wojewoda *et al*. 2011). The average annual air temperature is 4.8°C, the average temperature in July is 16.9°C, whereas the average temperature in January is -7.3°C (Otop and Miszuk 2011). The mean annual precipitation varies between 750 to 920 mm (Gałka *et al*. 2014). Peatlands, thus organic soils cover is estimated on 132 ha, equivalent to 2.5% of the Stołowe Mountains surface (Glina *et al*. 2017). The study peatland (transitional bog) is located in the central part of the Stołowe Mountains (Fig. 1b). This area is surrounded by the Białe Skały massif with cliff section of sandstone outcrops (Duszyński *et al*. 2016). As a result of constant sandstones weathering, this area is periodically covered by sand material (transported by water in the period of intense rainfall), present in the peat cores as mineral interlayers (Fig. 2).

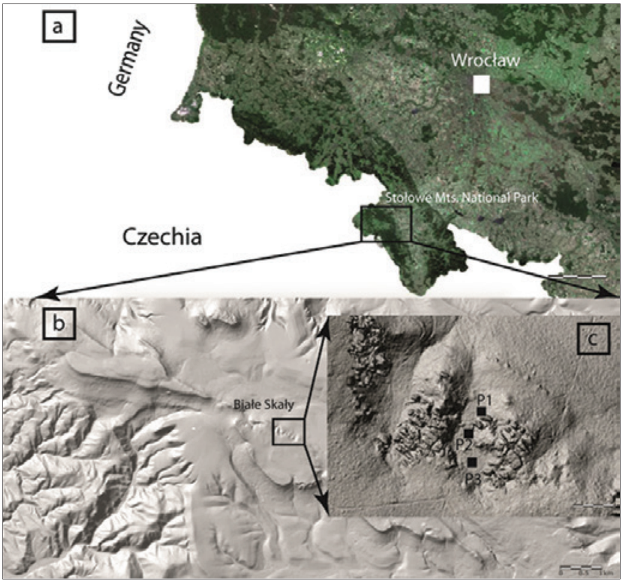

Fig. 1. Location of the Stołowe Mountains (a), the Białe Skały massif (b) and soil profiles within the study area (c)

FIELD SURVEY AND LABORATORY ANALYSIS

Field survey and soil sampling were conducted in August 2015 within the area of transitional bog under Białe Skały (Fig. 1b). To achieve research goals, 3 sampling plots were established (Fig. 1c) and located in a different length from the sandstone cliffs to track impact of sandy strata. Peat cores from each sampling plot were extracted using an "Instorf" peat corer, that sampled cores of around 50 cm long (diameter 5.2 cm). In the study, two organic soils (profile 1 and 2) with mineral interlayers and one reference organic soil (profile 3) devoid

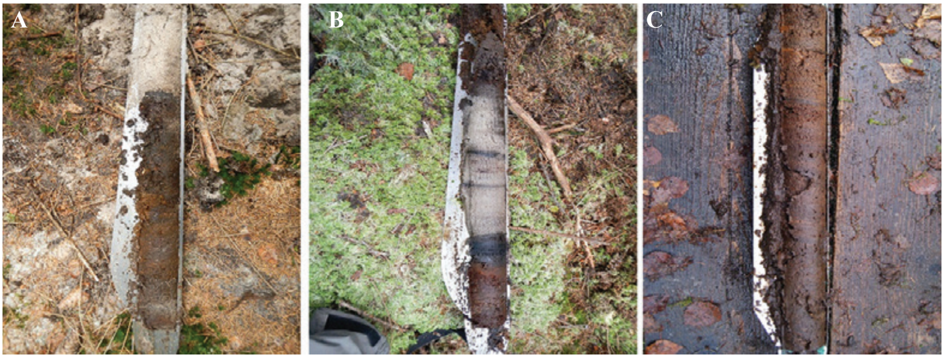

Fig. 2. Peat cores sections: profile 1 (A) and profile 2 (B) reveal visible mineral interlayers, while profile 3 (C) consists of organic strata only

of mineral admixtures, were used. The soils were described according to the Field guide for soil description (SSSP 2017) and classified with the Polish Soil Classification (PSC 2011) and FAO-WRB system (IUSS Working Group 2015). Soil samples for laboratory analysis were sampled by genetic soil horizons. Before the laboratory analysis each soil sample was divided into two parts. In fresh (moist) material the degree of peat decomposition was determined using two methods: percentage content of rubbed fiber and SPEC – sodium phyro-posphate index color, described in detail by Lynn *et al.* (1974). The rest of the soil samples were dried at 105°C, mixed and plant remains were removed. In dry soil material, the following parameters were analyzed: ash content after placing dried samples for 5h in a muffle furnace at 550^{o}C (Bojko and Kabala 2014), particle density calculated using Zawadzki's formula (Okruszko 1971), total organic carbon (TOC) and nitrogen (TN) using Vario Max analyzer, soil pH (in KCl and distilled water) using a solution ratio of 1:2.5 (soil: water ratio 1:2.5) potentiometrically (Kabala *et al*. 2016), content of exchangeable base cations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}) extracted with 1 M ammonium acetate at pH=7 using AAS analyser (van Reeuwijk 2002), content of acid cations (H^{+}, Al^{3+}) extracted with 1 mol dm^{-3} KCl using titration method (van Reeuwijk 2002). Based on exchangeable cations analysis cation exchange capacity (CECe) and base saturation (BS) were calculated. Except of "disturbed" soil samples, also undisturbed samples for bulk density determination were collected to stainless steel rings (100 cm^{3}). Particle-size distribution in mineral material (sand) was conducted using sieves for sand separation and the hydrometer method for silt and clay fractions (van Reeuwijk 2002).

RESULTS AND DISCUSSION

Morphology and classification of the studied soils

Soil profiles 1 and 3 in accordance with the Polish Soil Classification (PSC, 2011), were classified as hemic-fibric peat soil (in Polish: *gleba torfowa hemowo-fibrowa*), whereas profile 2 – as sapric-hemic peat soil (in Polish: *gleba torfowa saprowo-hemowa*) (Table 1). Due to the international FAO-WRB classification (IUSS Working Group, 2015), soils under study belonged to reference group of Histosols, with addition of various principal and supplementary qualifiers (please see Table 1). In the soil profiles 1 and 2, the presence of mineral contribution or even thick single mineral (sand) interlayers was recorded (Fig. 2, Table 1). It is the result of removing sand from weathered sandstone cliffs, which surround the studied peatland. In the FAO-WRB system (IUSS Working Group, 2015), the presence of mineral layers, or contribution of such substrates into organic soils is indicated by Mineralic supplementary qualifier (if combined thickness of mineral layers is ≥20 cm). However, in the PSC (2011), classification of such soils is problematic, in particular of fibric peat soils type. This work showed the next example of organic soils which currently do not have their taxonomy position in PSC (2011).

TABLE 1. SOIL MORPHOLOGY AND CLASSIFICATION

Soil horizon	Depth (cm)	Material	Color (moist)	Structure	Soil moisture	Horizon boundary
Profile 1 *gleba torfowa hemowo-fibrowa* (PSC 2011) Dystric Ombric Hemic Fibric Histosol (Mineralic) (WRB 2015)						
Oe1	0–5	hemic peat	10YR 2/1	A-F	moist	A,S
C1	5–21	sand	10GY 7/10	SG	wet	A,S
Oe2	21–26	hemic peat	10YR 3/2	A-W	wet	C,S
Oi1	26–37	fibric peat	7,5YR 4/4	F	wet	C,W
Oe3(p+s)	37–40	hemic peat	10YR 3/2	A-W	wet	A,S
C2	40–45	sand	10GY 7/10	SG	wet	A,S
Oi2(p+s)	45–53	fibric peat	10YR 4/6	F-S	wet	C,W
Oe4	53–61	hemic peat	7,5YR 3/2	A-F	wet	C,W
Oi3	61–80	fibric peat	7,5YR 4/4	F-S	wet	G
Oi4	80–100	fibric peat	7,5YR 4/4	F-S	wet	G
Oe5	100–115	hemic peat	10YR 3/3	A-F	wet	–
Profile 2 *gleba torfowa saprowo-hemowa* (PSC 2011) Dystric Ombric Hemic Fibric Histosol (Mineralic) (WRB 2015)						
Oe1	0–10	hemic peat	10YR 2/1	F	moist	G
Oi(p+s)	10–27	fibric peat	7,5YR 3/4	F-W	moist	C,S

Soil horizon	Depth (cm)	Material	Color (moist)	Structure	Soil moisture	Horizon boundary
C1	27–46	sand	10GY 7/10Y	SG	wet	C,S
Oe2	46–51	hemic peat	10YR 3/3	A-F	wet	C,W
Oa1	51–57	sapric peat	10YR 2/1	A	wet	C,S
C2	57–61	sand	10GY 5/10	SG	wet	C,S
Oe3	61–78	hemic peat	7,5YR 3/3	A-F	wet	C,W
Oa2	78–84	sapric peat	10YR 2/2	A	wet	C,S
C3	>84	sand	10GY 5/10Y	SG	wet	–
Profile 3 *gleba torfowa hemowo-fibrowa* (PSC 2011) Dystric Ombric Hemic Fibric Histosol (WRB 2015)						
Oe1	0–16	hemic peat	10YR 3/1	A-F	wet	G
Oi1	16–26	fibric peat	10YR 5/6	F	wet	C,W
Oe2	26–67	hemic peat	10YR 3/4	A-F	wet	G
Oi2	67–120	fibric peat	10YR 4/4	F-W	wet	–

Explanation: p+s – peat + sand, structure: SG – single grain, A – amorphous, F – fibrous, S – spongy, W – woody horizon boundaries: A – abrupt, C – clear, G – gradual, S – smooth, W – wavy

Mentioned problem was described in detail by Glina and Bogacz (2016) in the review paper about selected issues related to the classification of mountain organic soils.

Physical properties of studied soils

Based on rubbed fiber (RF) content organic soils under study consisted of strongly (sapric), moderately (hemic) to slightly (fibric) decomposed peat material which alternately occurs in the profiles (Table 2). In the case of soils 1 and 2 organic layers directly below the mineral layers (C1, C2 – profile 1 and C1, C2 – profile 2) have a lower stage of peat decomposition (hemic – Oe2, Oe3 or even fibric Oi2). It might indicate that sand cover inhibits the decomposition of organic matter, accumulated organic material was fast covered which was also reported by Bogacz and Rutkowska (2010). Ash content in organic horizons ranged between 5.0 to 60.1%. The highest content were observed in organic horizons with admixture of sandy material (Table 2), whereas the lowest values typical for slightly decomposed peat (Nichols and Boelter 1984) were recorded in the profile 1, free of sand material (Table 2, Fig. 2c). Similar tendency was observed in relation to bulk density (BD) and particle density (PD) values. The lowest BD and PD was recorded in profile 3 (0.10–0.14 g cm^{-3}, 1.47–1.57 g cm^{-3}), while the highest in organic horizons in profile 1 (0.22–0.33 g cm^{-3}, 1.79–2.11 g cm^{-3}). Reported results meet the data published by Bogacz (2005), Bogacz and Roszkowicz (2010), Bogacz and Rutkowska (2010), who described higher BD and

SG in organic layers with mineral admixtures in organic soils from the Stołowe Mountains and other Sudetes ranges.

TABLE 2. SELECTED PHYSICAL PROPERTIES OF STUDIED SOILS

Profile No.	Soil horizon	Depth (cm)	PI	RF	Ash	PD	BD
				%		g cm^{-3}	
1	Oe1	0–5	4	36	44.8	1.94	0.27
	C1	5–21	–	–	99.3	2.54	1.29
	Oe2	21–26	6	36	46.8	1.97	0.28
	Oi1	26–37	6	42	49.0	1.99	0.29
	Oe3(p+s)	37–40	5	30	60.1	2.11	0.33
	C2	40–45	–	–	99.2	2.54	1.31
	Oi2(p+s)	45–53	5	60	58.7	2.10	0.33
	Oe4	53–61	5	64	44.2	1.94	0.27
	Oi3	61–80	5	50	36.5	1.85	0.24
	Oi4	80–100	5	44	31.1	1.79	0.22
	Oe5	100–115	3	28	45.8	1.95	0.27
2	Oe1	0–10	5	20	22.1	1.69	0.18
	Oi(p+s)	10–27	6	42	53.1	2.04	0.30
	C1	27–46	–	–	97.5	2.52	0.68
	Oe2	46–51	5	24	51.8	2.02	0.30
	Oa1	51–57	2	5	56.8	2.08	0.32
	C2	57–61	–	–	63.8	2.15	0.55
	Oe3	61–78	5	25	31.8	1.80	0.22
	Oa2	78–84	3	3	58.8	2.10	0.33
	C3	>84	–	–	95.6	2.50	0.57
3	Oe1	0–16	6	38	11.1	1.57	0.14
	Oi1	16–26	7	45	5.0	1.51	0.11
	Oe2	26–67	5	35	11.1	1.57	0.14
	Oi2	67–120	7	45	1.9	1.47	0.10

Explanation: PI – phyrophosphate index, RF – rubbed fiber content, PD – particle density, BD – bulk density

Physicochemical and chemical properties of studied soils

The soil reaction is, in general, strongly acidic throughout the studied soil profiles, moreover, no dependency between soil depth and pH values were observed (Table 3). The measured pH values vary within the range from 2.60–3.50 (in 1 mol dm^{-3} KCl solution) and 3.10–4.25 (in H_2O solution). Higher pH values were observed in sand interlayers and organic horizons adjacent to those layers, what clearly indicated the impact of mineral material admixtures on organic soils reaction. Similar pH values were recorded in organic soils in other transitional bogs in the Sudetes (e.g. Bogacz 2005, Bogacz and Rutkowska 2010, Glina *et al*. 2016b), moreover, in these papers also the influence of mineral admixtures were reported. The total organic carbon (TOC) content in soil horizons was estimated between 25.5 to 472 g kg^{-1} (Table 3). The mean TOC content in the "pure" organic layers were greatly higher than in the horizons with mineral admixtures. The same situation was observed in relation to total nitrogen (TN) content, which was in the range from 1.50 to 14.8 g kg^{-1}. In addition to the apparent influence of mineral admixtures on these properties, also some dependency on the stage of peat decomposition is noticeable. In soil horizons consisted of slightly decomposed peat (fibric), TOC content was higher than in strongly decomposed peat material (sapric). In the case of TN content the dependency was inverse. Calculated TOC/TN ratio (26.2–57.9), used as an indicator of the mineralization of organic matter, indicates very weak or even lack of this process. As it was suggested by Bogacz (2005), intensive mineralization of organic matter occurs when TOC/TN ratio is below 20.

Exchangeable acidity (H_{ex}) and exchangeable aluminum (Al_{ex}) content in the soils of the transitional bog vary over a range: 1.60–11.6 and 1.20–31.8 cmol (+) kg^{-1}, respectively.

There is a close relationship between aluminum and hydrogen content versus mineral material. In the profiles 1 and 2 recorded values were lower than in the reference peat soil (profile 3). In the studied organic soils, exchangeable acid cations predominated over exchangeable base cations, which constituted the following affinity series (Ca^{2+}>Mg^{2+}>Na^{+}>K^{+}), similar to other organic soils from the Central Sudetes (Bogacz 2005, Glina *et al.* 2013). Among the analyzed base, cations calcium is predominant (0.78–2.56 cmol (+) kg^{-1}) in both mineral and organic soil horizons (Table 3). In organic soils developed on sandstone bedrock or with sand admixtures within soil profiles from the Sudetes (Bogacz 2005) and Guayana Highlands (Zinck and Garcia 2011), higher content of sodium than potassium were observed. It interacts with our findings. As it was observed in profiles 1 and 2, the fact that the amount of sodium is below the potassium level is a general case. However, slightly increase of sodium amount in organic horizons adjacent to mineral layers were observed (Table 3). The cation exchange capacity (CECe) varies within wide range (5.03–45.2 cmol (+) kg^{-1}), recorded values were higher in peat soil without sand layers (profile 3) than in the profiles 1 and 2. The CECe mainly depends on aluminum and hydrogen content which dominated among exchangeable cations. This observation confirmed highly oligothrophic status of study peatland soils (Bogacz and Rutkowska 2010). Effective base saturation (BS) was calculated on the basis of the sum of exchangeable base cations and exchangeable acidity. Mean BS was at ca. 14.5%, but it varied over a range from 7.00 (in fibric peat) to 28.8 % (in mineral layer). Higher BS value recorded in organic layers directly below and above mineral layers indicated the influence of sand admixtures on this soil parameter, which was also postulated by Bogacz and Rutkowska (2010), based on the organic soils investigation from Krągłe Mokradło bog in the Stołowe Mountains.

TABLE 3. SELECTED PHYSICOCHEMICAL AND CHEMICAL PROPERTIES OF STUDIED SOILS

Profile No.	Soil horizon	Depth (cm)	pH H_2O	pH KCl	TOC	TN	TOC/TN	H_{ex}	Al_{ex}	Ca^{2+}	Mg^{2+}	K^+	Na^+	CECe	BS
					g kg^{-1}			cmol(+) kg^{-1}							%
	Oe1	0–5	3.60	2.80	280	11.9	23.5	8.40	7.00	1.62	1.08	1.53	0.65	20.3	24.1
	C1	5–21	3.80	3.00	39.7	1.50	26.5	2.40	2.01	1.10	0.39	0.11	0.18	6.18	28.8
	Oe2	21–26	3.50	2.70	192	5.40	35.5	11.6	3.40	2.08	0.04	0.12	0.4	17.6	15.0
	Oi1	26–37	3.50	2.70	178	5.25	34.0	2.20	20.2	1.60	0.05	0.06	0.22	24.3	7.90
	Oe3(p+s)	37–40	3.60	2.90	135	4.15	32.4	1.60	14.0	1.44	0.07	0.05	0.18	17.3	10.0
1	C2	40–45	3.80	3.10	66.0	1.90	34.7	2.40	1.40	0.96	0.09	0.04	0.14	5.03	24.5
	Oi2(p+s)	45–53	3.60	2.90	176	4.53	38.9	4.80	6.20	1.52	0.04	0.05	0.18	12.8	14.0
	Oe4	53–61	3.40	2.70	177	4.15	42.7	1.60	10.2	1.76	0.10	0.09	0.23	13.9	15.6
	Oi3	61–80	3.20	2.60	213	4.45	48.0	2.20	16.2	1.36	0.41	0.04	0.15	20.4	9.60
	Oi4	80–100	3.10	2.60	121	4.21	28.7	5.60	6.80	1.60	0.57	0.10	0.18	14.9	16.5
	Oe5	100–115	3.30	2.70	148	5.30	27.3	7.00	9.00	1.45	0.52	0.09	0.19	18.3	12.3
	Oe1	0–10	3.65	2.86	361	13.2	27.3	8.40	13.8	1.43	0.97	1.32	0.34	26.2	15.5
	Oi(p+s)	10–27	3.85	2.90	341	7.64	44.6	9.20	8.60	1.21	0.76	0.65	0.23	20.7	13.8
	C1	27–46	4.25	3.50	114	3.30	34.5	4.00	1.20	0.92	0.31	0.13	0.12	6.68	22.2
	Oe2	46–51	3.99	3.11	276	8.86	31.2	7.40	8.00	1.60	0.57	0.10	0.18	17.9	13.7
2	Oa1	51–57	4.23	3.32	296	11.3	26.2	3.20	30.4	2.48	0.41	0.27	0.15	36.9	9.00
	C2	57–61	3.93	3.04	113	4.44	25.5	4.60	2.20	1.03	0.45	0.18	0.19	8.65	21.4
	Oe3	61–78	3.51	2.86	322	8.80	36.6	8.20	14.0	2.56	0.67	0.15	0.12	25.7	13.6
	Oa2	78–84	3.89	3.01	251	9.43	26.7	5.40	8.80	1.67	0.49	0.19	0.13	16.6	14.9
	C3	>84	–	–	183	0.61	29.8	3.21	2.82	0.78	0.51	0.09	0.10	7.51	19.7
	Oe1	0–16	3.56	2.64	421	14.8	28.3	11.6	31.6	1.37	0.45	0.04	0.13	45.2	4.40
3	Oi1	16–26	3.58	2.69	440	9.07	48.5	10.4	31.8	1.28	0.5	0.06	0.11	44.2	4.40
	Oe2	26–67	3.84	2.88	442	32.0	32.0	9.80	28.8	1.96	0.65	0.13	0.18	41.5	7.00
	Oi2	67–120	3.81	2.90	472	8.15	57.9	8.20	23.0	2.03	0.67	0.09	0.15	34.1	8.60

Explanation: CECe – cation exchange capacity, BS – base saturation

CONCLUSIONS

1. Mineral admixture affects the properties of studied organic soils. The observed changes mainly related to organic horizons adjacent to mineral interlayers.

2. Among analyzed soil properties the stronger influence of mineral admixtures is related with organic matter content, exchangeable acid cations and base saturation.

3. The frequency and periods of mineral material deposition in the Białe Skały area is an interesting issue to consider in the future, in the context of radiocarbon and palaeoecological research.

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