Rural high-quality development in Tibetan Plateau:

A key to tackle climate crisis rapidly

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Abstract: Rapidly removing huge amounts of atmospheric CO2 is extremely critical to tackle climate crisis. Numerous approaches had been therefore proposed to try to quickly stabilize atmospheric CO2 concentrations. However, most of them are hardly working well, largely due to little understanding of the changing mechanisms of atmospheric CO2 levels. Here we report the typically negative carbon-climate feedbacks between the growing Tibetan Plateau triggered off by the continuous collision between Indian and Asian continents and global climate change that are mechanisms to stabilize atmospheric CO2 levels really. During periods of global warming in Earth's history (interglacial periods), the growing Tibetan Plateau was a giant green water tower because it was a huge heat source. Large amounts of atmospheric CO2 quickly converted into carbonates, CO2-rich fluids/magmas, and organic matter were sequestered in the Tibetan thickened crust and surrounding foreland basins by various Tibetan geological processes, leading to the large drop of atmospheric CO2 levels since the Eocene-Oligocene transition, that were therefore regarded as Tibetan geological carbon sink. The growing Tibetan Plateau thus became the only nascent carbon reservoir worldwide. During periods of global cooling (glacial times), the growing Tibet Plateau underwent rapidly extensive desertification because it was a huge cold source, and consequently hardly absorbed any atmospheric CO2. Quite the opposite, a huge amount of CO2 was consecutively released from the only nascent carbon reservoir. Surface average temperature therefore started to rise, helping Earth out of the snowball state. Although currently most Tibetan regions are barren deserts where local living conditions are extremely poor due to the shortage of food, freshwater and oxygen particularly amid winter, huge amounts of atmospheric CO2 are still removed quickly by a handful tectonically active freshwater-enriched silicate regions, leading to the decline of annual growth rates of global mean atmospheric CO2 concentrations in the space of huge anthropogenic emissions. When more and more Tibetan barren deserts are quickly transformed to the planting wetlands artificially, the living conditions of Tibetan rural regions are, no doubt, greatly improved, largely due to sufficient food, freshwater and high oxygen concentrations provided by the newly-formed wetlands. More importantly, the Tibetan geological carbon sink is greatly enhanced simultaneously due to the renascent wetlands, and thus global carbon neutrality is achieved quickly and cheaply based on the negative carbon-climate feedbacks, no matter how much anthropogenic emissions in the near future. Therefore, high quality development of Tibetan rural regions is extremely critical to tackle global climate crisis quickly.

Key words: Climate crisis; high-quality development; negative carbon-climate feedbacks; Tibetan geological carbon sink; Tibetan rural regions

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1. Introduction

Atmospheric CO2 concentrations are close to 420 ppmv and thus extreme heatwaves scorch northern hemisphere, leading to severe consequences such as large-scale droughts and wildfires, particularly shortage of food and freshwater around the North Atlantic, as well as death of thousands of persons, warning us to stabilize atmospheric CO2 concentrations as soon as possible. However, anthropogenic carbon emissions are still rapidly escalating, such as restarting low-quality-coal power plants in several developed countries, as well as the releasing of large amounts of much more dangerous greenhouse gas, methane, by the sabotage of large-scale gas pipelines. We have to wrestle with much more tough global climate challenges in the near future. Fast and cheap removal of massive anthropogenic emissions is therefore an urgent need worldwide. Numerously approaches have been therefore used to try to stabilize atmospheric CO2 concentrations (Hepburn et al., 2019). For example, the CO2 gas with high concentrations from condensed flue gas or other enriched sources have been subsequently injected into deep regions, particularly into deep oil reservoirs (Hepburn et al., 2019). A large amount of silicate powder is scattered to croplands (Beerling et al., 2020), grasslands and forests as an alternative approach to try to remove additional atmospheric CO2 (Hepburn et al., 2019). Unfortunately, these traditional approaches normally require extremely high energy and infrastructure inputs every year (Beerling et al., 2020; Hepburn et al., 2019) so that they are hardly working well today, largely due to unknowing of what mechanisms are really responsible for rapidly net uptake of atmospheric CO2, despite it has been well known for a long time that negative carbon-climate feedbacks stabilized Earth ' s long-term climate (Walker et al., 1981; Berner et al., 1983; Zeebe and Caldeira, 2008) and, in particular, atmospheric CO2 levels (Ballantyne et al., 2012; Ciais et al., 2019). Therefore, in-depth understanding of the mechanisms controlling the historically changing processes of atmospheric CO2 concentrations is, no doubt, critical to cheaply achieving global carbon neutrality fast. Numerous studies have previously revealed that during the Eocene, the atmospheric CO2 concentrations were approximately 5 times that for today (e.g., Zachos et al., 2008; DeConto et al., 2008). During the Eocene-Oligocene transition, atmospheric CO2 concentrations plummeted quickly down, leading to the formation of the Antarctic ice sheets (e.g., Pearson et al., 2009; Pagani et al., 2011). Earth therefore enters the stages of glacial-interglacial climates from warming-house climates (e.g., Arrhenius, 1896; Chamberlin, 1899; Raymo and Ruddiman, 1992; Edmond, 1992). However, it still remains controversial where huge amounts of atmospheric CO2 sink (e.g., Sundquist, 1993; Berner and Caldeira, 1997; Zachos et al., 2008; Zeebe and Caldeira, 2008). From a global mass balance perspective, it clearly suggests that at least one unknown carbon reservoir has continuously accommodated the huge amounts of atmospheric CO2 since the late Eocene. More importantly, it still remains obscure whether huge amounts of anthropogenic emissions can be quickly removed. These questions critical to the public worldwide are well addressed in this study. And it has been clearly illustrated how quickly and cheaply the large amounts of anthropogenic emissions are transformed to massively nascent carbonates and relatively minor organic carbon matters. Subsequently the cheapest approach is present here to rapidly stabilize atmospheric CO2 concentrations regardless of how much anthropogenic emissions in the near future.

2. Materials and methods

2.1 Data acquisition and analysis

The entire Tibetan Plateau and its adjacent regions are research regions in this study where multidiscipline comprehensive surveys have been performed (Figure 1). In order to quantitatively evaluate carbon uptake capacity of the critical regions (Figure 1) in the context of massive anthropogenic emissions today, abundantly observational multidisciplinary data were collected for comprehensively contrastive analyses. Horizontal shortening rates between Indian and Asian continents (Figure 1) were from Wang and Shen (2020), indicating the deformative intensity of crust triggered off by the consecutive collision between Indian and Asian continents. From south to north roughly, the crustal deformation is gradually decreasing (Wang and Shen, 2020). The Waliguan in the Figure 1 is a professional station recording atmospheric CO2 concentrations, situated on the top of Mt. Waliguan on the NE Tibetan Plateau, far away from modern industry. Therefore, the atmospheric CO2 concentrations recorded by the station reflected those affected by Tibetan Plateau.

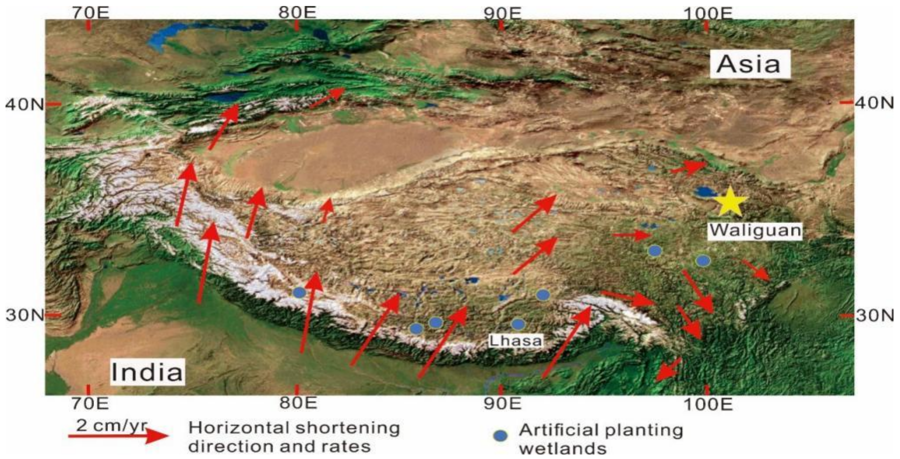

Figure 1 sketch map showing crustal horizontal shortening direction and rates (red arrow), as well as artificially planting wetlands (blue cycles), in the studying region. The studying regions are dominated by barren deserts that are yellow and/or brown yellow. Salty lakes are small irregular light blue or blue areas within the yellow and/or brown yellow regions. Green regions are covered by various plants. White areas are covered by snow and/or ice sheets.

The originally monthly mean atmospheric CO2 data recorded by the Hawaii station and the Waliguan station, respectively, were collected from the NOAA (https://gml.noaa.gov). Annual growth rates (bottom to bottom) of the monthly mean atmospheric CO2 concentrations were acquired by the lowest value in a year, normally the summer's value, deducted the lowest one in the previous year. Whereas the annual growth rates (peak to peak) were gotten by the highest value in a year, normally the spring's value, minus the highest one in the previous year. All of them are shown in the Figure 2a. The EXCEL software was used to make a regression analysis on the annual growth rates (peak to peak) between the Hawaii and Waliguan stations (Figure 2b).

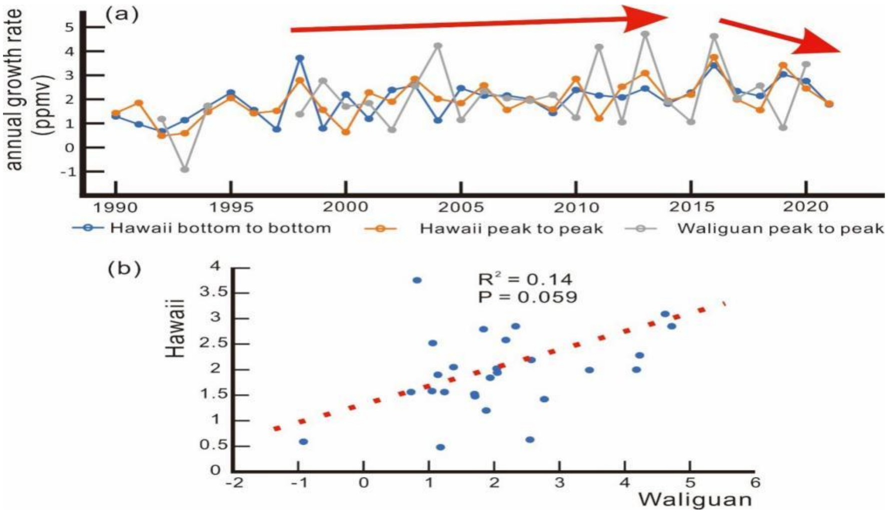

Figure 2 (a) Annual growth rates of atmospheric CO2 concentrations recorded by the Hawaii and Waliguan stations, respectively, over the past 30 years. (b) Trends of annual growth rates (peak to peak) of atmospheric CO2 concentrations recorded by the Hawaii and Waliguan stations, respectively, over the past 30 years.

2.2 Tibetan carbon sink estimations

Two completely different methods were used to evaluate the carbon uptake by Tibetan Plateau in this study. The first approach is from Liu (2021). The primary reason for this method is that large amounts of atmospheric CO2 had been rapidly turned into massively secondary carbonates and organic carbon that are subsequently buried in the thickened crust and its adjacent foreland basins by the uniquely geological processes (Liu, 2013; 2019; 2021). The carbon uptake can be therefore acquired by the direct measurements on the contents of the secondary carbonates and organic carbon in soils and rocks beneath the soils within Tibetan Plateau and its adjacent foreland basins (Liu, 2021). The calculated formula for this estimation is following:

$F = \rho * S * f * (Corg + Cinorg) + Q$

Where:

F = annual total atmospheric CO2 uptake (in tonne);

ρ =average density (in tonnes per cubic meter);

S =average annual carbon burial rate (in millimeter per year), normally 1-2 millimeters per year due to horizontal shortening rates of 2 centimeters per year (Wang and Shen, 2020);

f =area of regions (in hectare);

Corg = buried organic carbon contents (in weight percent);

Cinorg = buried inorganic carbon contents (in weight percent);

Q = organic carbon over surface, roughly corresponding to the traditional ecosystem carbon sink (in tonnes per year).

The changing of CO2 concentrations (in ppmv) was used as the second method that is relatively simple to estimate the carbon uptake by the entire Tibetan Plateau and its adjacent regions in this study. The annual carbon uptake rates listed in the Figure 2 roughly represent the net carbon uptake by these critical regions within one year. 1 ppmv = 7.782 gigatonnes atmospheric CO2 (Friedlingstein et al., 2021).

3. Results

3.1 Negative carbon-climate feedbacks between the growing Tibetan Plateau and global climate change

The persistent convergence between Indian and Asian continents has created the growing Tibetan Plateau (Figure 1). Gravity isostasy suggests that high topography corresponds to thickened crust, and vice versa. Therefore, the formative ages of the oldest thickened crust are generally regarded as the originally uplifting times of the proto plateau (Liu et al., 2007a). Previous studies have revealed that the oldest Tibetan thickened crust as a result of the continuous India-Asia collision (Liu and Zhong, 1997) had been formed during the Eocene-Oligocene transition (e.g., Liu et al., 2007a; 2007b; Zhang et al., 2017), exactly corresponding to the formation of the Antarctic ice sheets (Pearson et al., 2009; Pagani et al., 2011). It has thus confirmed the previous view that the uplift of Tibetan Plateau really led to the global cooling and subsequent formation of the Antarctic ice sheets, largely due to intensive silicate chemical weathering (Arrhenius, 1896; Chamberlin, 1899; Raymo and Ruddiman, 1992; Edmond, 1992).

During global warming times (interglacial periods), Tibetan Plateau was easily heated up by sunlight to become a huge heat source (e.g., Lehmkuhl and Haselein, 2000; Liu, 2019; 2021). And much freshwater was therefore towards Tibetan Plateau so that the previously barren Tibetan regions (e.g., Figure 1 and 3) were quickly disappeared or even transformed to planting wetlands. Tibetan Plateau became a giant green water tower (e.g., Liu, 2021).

Figure 3 Field photo showing the typically negative carbon-climate feedbacks between the growing Tibetan Plateau and global climate change. When atmospheric CO2 levels rise, surface mean temperature is increased due to the enhanced greenhouse effects. The growing Tibetan Plateau is therefore heated by sunlight to become a huge heat source easily, and thus, much freshwater is towards the growing Tibetan Plateau, leading to the expansion of inland ice sheets. Tibetan cracked granitoids in the barren deserts have been therefore transformed into organic-bearing soils quickly by the coupled active plant roots and tectonics through the simply chemical reaction mentioned in the text, resulting in the rapid removal of large amounts of atmospheric CO2.

Under relatively high surface temperature, Tibetan plants were highly physiological active in the tectonically active silicate regions rich in freshwater (e.g., Figures 3-6). And huge amounts of atmospheric CO2 were thus rapidly consecutively sent to the subsurface cracked silicate regions by the physiologically active plant roots. Within the 3D space rather than the 2D space where the conventional silicate chemical weathering took place, the subsurface cracked silicates chemically reacted completely with the large amounts of organic and carbonic acids with high concentrations exuded by the physiological active plant roots (e.g., Figures 3-6). This process can be approximately described using the following simply chemical reaction:

$CaAl2Si2O8 + 3H2O + 2CO2 \rightarrow CaCO3 + Al2Si2O5(OH)4 + CH2O + O2$

All weaknesses of the traditional silicate chemical weathering are perfectly overcome by the simply chemical reaction, such as very short residence time of atmospheric CO2 with very low concentrations for the silicate chemical weathering reactions, extremely small surface areas available for these chemical weathering reactions, conventionally higher pH values against the reactions, and relatively low temperature for the chemical reactions. Therefore, the chemical reaction is quickly run in the tectonically active silicate regions rich in freshwater (e.g., Figures 3-6) and subsequently vast atmospheric CO2 are rapidly transformed to massive secondary carbonates and relative low contents of organic materials (e.g., Figure 6). Moreover, the newly-formed organic materials (CH2O in the simple chemical reaction mentioned-above) were normally protected well by the nascent clay minerals (Al2Si2O5(OH)4 in the simple chemical reaction), as well as the secondary carbonates (CaCO3 in the reaction), to avoid the reoxidation to release CO2 by the physiologically active plant roots beneath surface, and thus, form the dark organic-enriched soils generally (e.g., Figures 4 and 6).

Figure 4 Field photo has shown that the Tibetan dark organic-enriched soils have been generally formed by the enhanced chemical weathering of cracked silicates beneath surface, greatly assisted by the physiologically active grass roots in the freshwater-enriched tectonically active silicate regions through the simply chemical reaction mentioned in text in summer. Meanwhile, large amounts of atmospheric CO2 have been directly removed in a short time.

More importantly, these newly-formed carbon-abundant materials at the expense of huge amounts of atmospheric CO2 were further buried in the Tibetan thickened crust and its adjacent foreland basins (e.g., Figures 5-7) by the active tectonics triggered off by the continuously flat subduction of Indian continent below the growing Tibetan Plateau (Liu, 2013; 2019; 2021), and thus, are hardly back to atmosphere once again, leading to the rapid removal of huge amounts of atmospheric CO2. And hence, they are regarded as Tibetan geological carbon sink. Therefore, the growing Tibetan Plateau boasts a bottomless appetite for the capturing of large amounts of atmospheric CO2 continuously.

It should be pointed out that most of the deeply buried carbon-abundant materials (Figure 7) normally experienced intensive decarbonization, releasing the carbonic magmas rather than metamorphic CO2 gas (Liu et al., 2006) to the specific magma chambers in the Tibetan thickened crust (Figure 7), due to the flat subduction of Indian continent (Liu et al., 2006; Liu, 2013). The decarbonized relics in the deep regions were finally exhumated to shallow depth as little-weathered cracked silicates (Figure 7), and then underwent the intensive carbonization such as the enhanced subsurface silicate chemical weathering (e.g., Figures 3-4) once again. Therefore, at least 7 trillion tonnes of atmospheric CO2 have been sequestered by the growing Tibetan Plateau since the Eocene-Oligocene transition. And thus, Tibetan Plateau becomes the only renascent carbon reservoir worldwide. The long-term imbalance between atmospheric inputs and outputs of CO2 mentioned-above could be perfectly accounted for by the fact that huge amounts of atmospheric CO2 had been persistently accommodated by the growing Tibetan Plateau.

Figure 5 Field photo showing that landslides normally took place along the active normal fault, leading to the tectonic burial of newly-formed massive carbon-abundant materials within the tectonically active freshwater-enriched silicate regions.

Figure 6 The newly-formed carbonates (light layers) and organic matter (dark) at the expense of huge atmospheric CO2 were buried in the Tibetan thickened crust by the active tectonics.

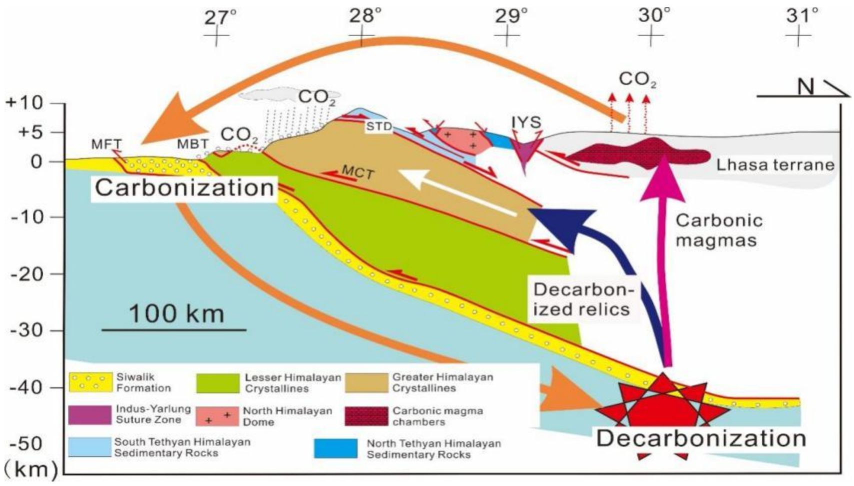

Figure 7 Sketch map showing how the growing Tibetan Plateau has become the only renascent carbon reservoirs worldwide, and thus, to stabilize atmospheric CO2 concentrations.

During global cooling times (glacial periods), Tibetan Plateau was hardly heated up by sunlight, largely due to highly weak greenhouse effects, and thus became a hugely cold source. Much surface water within Tibetan Plateau and its adjacent regions has been transported to high latitudes, resulting in rapid extensive desertification in Tibetan Plateau and its adjacent regions (Liu, 2019; 2021). The Chemical reaction described in the previous section was extremely weak owing to water shortage and relatively low surface mean temperature. Little atmospheric CO2 was therefore sequestered by the growing Tibetan Plateau amid the cooling periods. Quite the opposite, physical weathering became much stronger to make previous soil organic matter oxidization (e.g., Figure 8), releasing CO2 back to atmosphere. Moreover, large amounts of CO2 were released from the carbonic magma chambers within the thickened crust (Figure 7) through the Tibetan large-scale rift zones (e.g., Figure 9) to atmosphere. Therefore, Tibetan Plateau was a huge carbon source during the global cooling times, leading to the rising surface mean temperature and helping Earth out of snowball. The formation of Tibetan Plateau is thus an important global rather than regional event, dominating the fluctuation of atmospheric CO2 concentrations since the Eocene-Oligocene transition. Particularly it has stabilized atmospheric CO2 concentrations by the negative carbon-climate feedbacks since the late Pleistocene, which were in a narrow range of 300-180 ppmv (Zeebe and Caldeira, 2008).

Figure 8 Field photo showing that Tibetan previously organic-abundant soils (yellow brown) disappeared partially, and light-colored cracked granitoids below the soils were exposed, largely owing to the stronger physical weathering during global cooling times.

Figure 9 Large amounts of CO2 were released by the carbonic volcanoes in the Tibetan rift zones.

3.2 Rural development in Tibetan Plateau

Most Tibetan regions are barren deserts now (Figures 1, 10, 11) that are extremely poor, largely due to the shortage of food, freshwater, and particularly oxygen during winter. The net primary production in the Tibetan barren deserts is relatively low. For example, one Tibetan yak normally needs at least 2 hectares of grasslands per year (Figure 10b), resulting in food shortage normally. Local persons had to frequently move to other regions rich in freshwater. It should be pointed out that fossil studies (Huang et al., 2020; Qin et al., 2022) have revealed that the barren Tibetan Plateau and its adjacent regions were fully covered by rain-forests or grass-wetlands during the previously warming periods, leading to the decline of atmospheric CO2 concentrations during historically warming times (e.g., Liu, 2019; 2021). At that time, the entire Tibetan Plateau was a green giant water-tower (Lehmkuhl and Haselein, 2000; Liu, 2019; 2021; Huang et al., 2020; Qin et al., 2022). Food, freshwater, as well as oxygen concentrations were enough for living of large amounts of local persons. As discussed in the previous section in detail, recently global cooling led to the currently Tibetan barren deserts, and thus, global warming today will cause the completely disappearing of them in the future. Artificially planting wetlands will accelerate the transformation quickly (e.g., Figures 11-15).

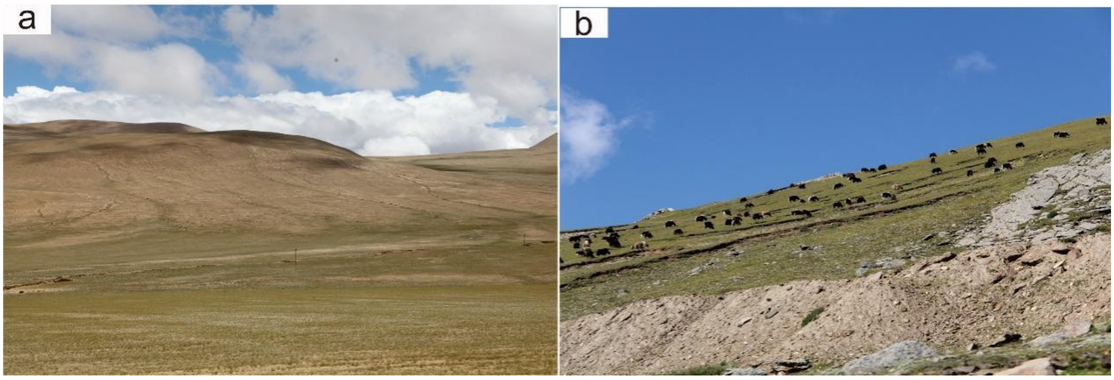

Figure 10 Field photos showing barren Tibetan regions currently, largely due to recent global cooling.

Figure 11 Pum Qu river goes through the deserted regions in the central-south Tibet. If a simple retaining dam is built in the nearby valley, the barren deserts here are quickly transformed to planting wetland, and thus, huge amounts of atmospheric CO2 are removed by the chemical reaction mentioned in the text.

Simple retaining dams built at special valleys is the only approach to rapidly transform large amounts of barren deserts to artificially planting wetlands because the plateau is relatively flat (Figures 11-15). The chemical reaction to remove large amounts of atmospheric CO2 discussed in the previous section in detail is therefore working actively to release abundant oxygen within the artificial planting wetlands (Figures 12-15). Local persons are enjoying the artificial wetland (Figure 13), largely owing to that there is a plenty of food, freshwater and oxygen provided by the artificial wetlands (Figures 12-15). Therefore, the local living conditions are greatly improved completely because of the artificially planting wetlands, providing an excellent case that rapid removal of large atmospheric CO2 could raise social development greatly.

Figure 12 Tingkye-Gampa catchment, an artificial wetland in the central-south Tibet. Local living conditions are therefore increased greatly.

Figure 13 An artificial wetland in the central-south Tibet. Local persons enjoy the parties normally held in the artificial planting wetland, largely due to relatively high oxygen concentrations provided by the artificial wetland.

Figure 14 The previously deserted regions are quickly transformed to agricultural lands within the Tingkye-Gampa catchment, in central-south Tibet. Food yields are greatly improved due to wealthy water provided by the artificial planting wetland. At the same time, large amounts of atmospheric CO2 are removed passively.

Figure 15 The previously barren deserted regions are transformed to agricultural regions in the Tingkye-Gampa catchment, central-south Tibet. Local living conditions are greatly improved due to sufficient food and freshwater provided by the artificial wetland, and thus, large amounts of atmospheric CO2 are removed simultaneously.

4. Discussions and Conclusions

The carbon uptake rates of the well-known carbon reservoirs worldwide have remained constant roughly or even decreased in recent decades (Friedlingstein et al., 2006; Le Que´re´ et al., 2007; Ballantyne et al., 2012; Hubau et al., 2020; Gatti et al., 2021; Wang et al., 2022), clearly indicative of positive carbon-climate feedbacks (Friedlingstein et al., 2006). However, the terrestrial carbon sink is stably increased (Ballantyne et al., 2012; Ciais et al., 2019; Friedlingstein et al., 2021). Based on the global carbon mass balance, these reduced sinks must be more than compensated for by an increase in the rate of at least an unfamiliar carbon uptake. As the only renascent carbon reservoir worldwide, Tibetan Plateau is the potential carbon uptake. However, most Tibetan Plateau are barren deserts now (Figures 1, 8, 10, 11) that are a carbon source rather than carbon sink. It is therefore a critical issue whether currently large anthropogenic emissions can be sequestered by the Tibetan geological processes within one year rather than one million years.

Here we report a weakly positive correlation between the annual growth rates of atmospheric CO2 concentrations recorded by Waliguan station in the NE Tibetan Plateau and those recorded by the Hawaii station (R2 = 0.14, p = 0.059, Figure 2), clearly suggesting that atmospheric CO2 concentrations are largely affected by Tibetan Plateau, the only nascent carbon reservoir worldwide. More importantly, the annual growth rates of the atmospheric CO2 concentrations recorded by the Hawaii and Waliguan meteorological stations, respectively, start to decline in the context of huge anthropogenic emissions. As aforementioned in detail, during summer, Tibetan plants are highly physiological active in the tectonically active freshwater-enriched silicate regions (e.g., Figures 3-6), including the artificial wetlands recently (Figure 1). Huge amounts of atmospheric CO2 are therefore removed quickly through the chemical reaction mentioned above (e.g., Figures 3-6). These observations are further confirmed by recent space-borne measurements of atmospheric CO2, revealing that the currently eastern Tibetan Plateau fully covered by various plants is a really huge carbon sink (Wang et al., 2020; Yang et al., 2021). Moreover, satellite remote investigations in combination with field surveys (e.g., Figures 3-6) have further confirmed that Tibetan barren regions are rapidly transformed to the planting wetlands (Lehmkuhl and Haselein, 2000; Liu 2019; 2021; Chen et al., 2019; Ke et al., 2022), due in large part to global warming (Lehmkuhl and Haselein, 2000; Liu 2019; 2021), clearly suggesting higher inputs of organic carbon to TibetanPlateau in succession (Ding et al., 2017; Zhu et al., 2019; Wei et al., 2021). Therefore, the recent decreasing of the annual growth rates of atmospheric CO2 concentrations (Figure 2) is completely due to the recently enhanced Tibetan geological carbon sink by the additionally planting wetlands transformed from the barren deserts (Figure 1), despite of rapidly large increasing of anthropogenic emissions (e.g., Friedlingstein et al., 2021). More importantly, according to the negative carbon-climate feedbacks, the Tibetan geological carbon sink can be further increased greatly by artificially transforming much more barren deserts to planting wetlands rapidly (e.g., Figure 1). Therefore, massive anthropogenic emissions can be really sequestered by the artificially enhanced Tibetan geological processes within one year.

According to the method in this study, within the southern Tibetan Plateau where the tectonics are the most active (Figure 1), at least 30 tonnes atmospheric CO2 are estimated to be passively removed per year by the grass wetlands (e.g., Figure 4) per hectare. It should point out that the surface organic matters are not considered in this study, as some of them were rapidly buried by the active tectonics (e.g., Figures 5-6) to easily yield double counting (Liu, 2021). This means the model results here are underestimated slightly.

The cost for the carbon uptake in this study is simply to construct the simple retaining dams at the specific valleys (e.g., Figure 11) that can be used for several tens of years. These simple dams are mainly made up of local silicate rocks with minor cement and steel. Their sizes are generally 200 to 500 meters in length, 10 to 20 meters in height, and mean 200 meters in width. Excess water can easily across the simple dams to downstream. The total cost is approximately 1 million RBM for the constructure of one simple retaining dam that can be used for 30 years. A simple retaining dam can quickly transform 200 square kilometers barren deserts at least to artificial planting wetlands, largely due to the relative flat plateau internal. Approximately 30 tonnes of atmospheric CO2 are removed per year per hectare by the grass wetlands (e.g., Figure 4). This means that it spends approximately 3 RMB to remove 60 tonnes atmospheric CO2 per year. Therefore, the carbon uptake cost is less than 0.1 RMB/tonne/year here. Certainly, if local dominant species such as willows and pine trees are numerously planted in the artificial wetlands using the traditionally cheap approach, the carbon uptake cost will be even lower. Compared with the previously well-known approaches (Beerling et al., 2020; Hepburn et al., 2019), this method is therefore the cheapest because of extremely low energy and infrastructure inputs every year. The global carbon neutrality is therefore achieved cheaply regardless of huge anthropogenic emissions in the near future. In addition, the mean global sea level hardly rises in the near future, as much freshwater is consecutively sent to Tibetan Plateau and its adjacent inland regions from ocean (Lehmkuhl and Haselein, 2000; Liu, 2019; 2021), and thus cannot be back to ocean once again, partially due to these simply artificial retaining dams.

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